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EXTINCTION OF TRACE CONDITIONED RESPONSES AS A FUNCTION OF THE SPACING OF TRIALS DURING THE ACQUISITION AND EXTINCTION SERIES *

BY BRADLEY REYNOLDS

Northwestern University

INTRODUCTION

In an earlier paper (11) a theory of trace conditioning was presented, and a report was made of experimental results which confirmed certain implications drawn from that theory. In the present paper we shall consider further implications of the theory and report the results of an investigation which was designed to test them.

The theory of trace conditioning developed in the paper referred to above may be reviewed for our present purposes by a statement of it in a general equational form. This is

$$^{M}{}_{S}H_{R} = f(T, W, s),$$

where

$^{M}{}_{S}H_{R}$ = the maximum of growth of an intervening variable, habit strength, which can conveniently be regarded here as the limit of a learning curve for a trace conditioned response, under optimal conditions.[1]

T = the delay between the evocation of a response and the reduction of a need incident at that moment, i.e., the delay of reinforcement.

W = the amount of need reduction, i.e., the goodness of the goal.

s = the magnitude of the stimulus trace.

* This article is part of a dissertation presented to the faculty of the Department of Psychology of the State University of Iowa in partial fulfillment of the requirements for the Ph.D. degree. The writer wishes to express thanks to Professor Kenneth W. Spence for his advice and assistance.

[1] The reader is referred to Hull (5) for a more complete discussion of this construct.

Since we shall be concerned in the main with the intervening variable s we may examine, now, this construct in some detail. Our assumption regarding s, stated in a general form, is as follows:

$$s = f(F, N', t'),$$

where

F = the frequency of presentation of a conditioned stimulus ($\dot{S}$) per unit of time.

N' = one less than the ordinal number of the presentations of $\dot{S}$, in a series of such presentations.

t' = a measure based upon the temporal interval between the conditioned stimulus ($\dot{S}$) and the unconditioned stimulus S'.

The specific equational form is assumed to be

$$s = Pe^{-[F(1-e^{-jN'})+ht']},$$

where

$N' = N - 1$.

N = the absolute number of presentations of $\dot{S}$, i.e., the number of trials.

F is as above.

$t' = (t)S' - ((t)\dot{S} - .45$ sec.).

(t) = time of occurrence.

e = base of common logarithms.

P, j and h are empirical constants.

In verbal terms, the equation states that the magnitude of the stimulus trace (s) will decrease with successive presentations of the conditioned stimulus. The rate of this decrease will be greater, the greater the frequency of presentation of $\dot{S}$ per unit of time. The limit s will approach, with increasing N, is determined by the frequency of presentation of the conditioned stimulus and the temporal interval between the conditioned and unconditioned stimulus. The limit of s will be lower, the faster the rate of presentation of the conditioned stimulus and the longer the interval between the conditioned and unconditioned stimulus. This may be clarified by the following diagram (Fig. 1).

In this graph t' is held constant, its value being that for a stimulus trace of interval between conditioned and unconditioned stimulus of 450 msc. (s_{450} msc.). The curves show decreases in magnitude of s_{450} msc. with increasing trials, for different values of F, the rate of presentation of the conditioned stimulus. When F approaches zero, i.e. with trials widely distributed, decreases in magnitude of s_{450} msc. with increasing trials approach zero and the plot of s_{450} msc. against N approaches a straight line parallel to the N axis. In other words, with widely distributed trials, the magnitude of a stimulus trace as

determined by a given interval between the conditioned and unconditioned stimulus, tends to remain unchanged. As the rate of presentation of the conditioned stimulus increases, the magnitude of the stimulus trace decreases more rapidly with increasing trials and approaches a lower limit.

Some implications of this theory which are related to extinction of trace conditioned responses will now be considered. The magnitude of a stimulus trace has been stated to be a function of the rate of presentation of the conditioning trials, decreasing rapidly when the rate of stimulus presentation is rapid and tending to remain at a maximum when presentations are widely spaced (Fig. 1). What this

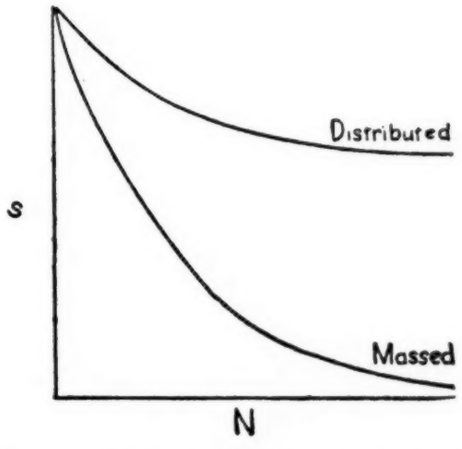

FIG. 1. Magnitude of a stimulus trace of constant t' under conditions of massing and distributing of trials

means is that with distributed presentations [2] the same magnitude of stimulus trace tends to appear with each presentation of the conditioned stimulus. When the rate of presentation of the conditioned stimulius is increased the magnitude of s changes rapidly. These new magnitudes presumably constitute different members of a stimulus trace dimension or continuum.[3]

Consider the following diagram (Fig. 2). The curves in the diagram represent a stimulus trace of a constant, or nearly constant, magnitude under the distributed condition of stimulus presentation, and a changing magnitude under the condition of massing. The point at which the magnitude changes is indicated by the vertical dashed line. The situation can be conceived to be analogous to one in which the intensity of a physical stimulus is changed in the direction of decreasing intensity.

[2] Distributed and massed as applied to the spacing of training trials in conditioning are relative designations. For the experiment reported here distributed means 1–2 min. between trials, massed 10–20 sec.

[3] *Cf.* Hull (5) for a discussion of the concept of stimulus dimension.

In an earlier paper (11), as noted above, rate and limit of growth of a hypothetical construct, habit strength, were assumed to be a function of three experimental variables, the rate of presentation of the conditioned stimulus, the interval between the conditioned and unconditioned stimulus, and the ordinal position of the stimulus presentation in a series of presentations. These characteristics of the stimulus trace lead to the following implication:

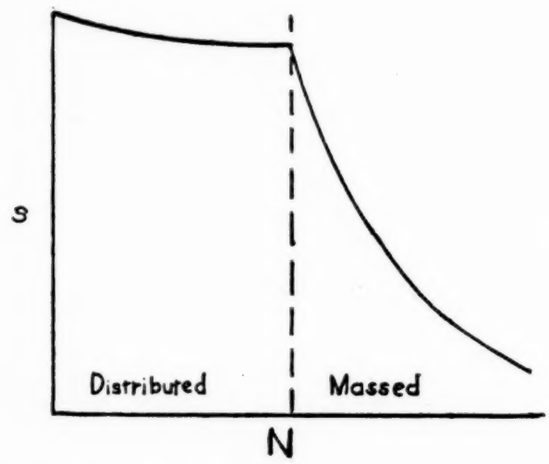

FIG. 2. Magnitude of a stimulus trace of constant t' under conditions of massing of trials following a period of distributing trials

If a trace conditioned response is set up with distributed trials, the same magnitude of stimulus trace tends to be reinforced at each trial. If, following acquisition, extinction is carried out with distributed trials, the magnitude of stimulus trace which is extinguished is that which has been reinforced. If extinction is carried out with massed trials, however, the magnitudes which are extinguished constitute different members of the trace dimension. Hovland (4) has furnished data which show that extinction of a response to a generalized stimulus is more rapid than extinction of a response to the stimulus which has been reinforced. It follows from this law and our theory that if acquisition has been with distributed trials massing of extinction trials will facilitate, and distribution of extinction trials retard, the extinction process. It should be noted that this implication holds for other types of conditioning than trace conditioning.

We turn now to the consideration of the implication of our theory for the reversed experimental procedure, i.e., acquisition under massed conditions and extinction under distribution of trials, where extinction immediately follows acquisition. At first glance it might seem that an experimental result the converse of the above implication would hold. It may be shown, however, that such an implication

cannot be drawn with any rigor. If a conditioned stimulus has been presented under conditions of massing the magnitude of s will have decreased rapidly with successive presentations of the conditioned stimulus. If the rate of presentation is then decreased the magnitude of s will increase with increasing trials. The magnitudes of s thus determined would constitute generalizations from the magnitudes of s appearing before the change in rate of presentation of the conditioned stimulus. This follows from the fact that the new rate of presentation will be determined in part by the old rate. An example will make this clearer. Assume a conditioned stimulus has been presented once per min. for 10 min. and the rate is changed to one per two min. Both rates may be stated at 10 per 10 min. and 5 per 10 min. and the presentations under the changed conditions of stimulation may be considered in terms of number per 10 min. The first presentation of the conditioned stimulus under the changed conditions would then be at the rate of 9 per 10 min., the second at the rate of 8 per 10 min., and so on. Consider the following diagram. The small circles represent stimulus presentations, the bar, a period of 10 minutes.

$\overline{\text{oooooooooo}}$ = 10 per 10 min.

$\overline{\text{ooooooooo}}$ o = 9 per 10 min.

$\overline{\text{oooooo}}$ o o = 8 per 10 min.

The magnitude of the stimulus trace rises through points on different curves for different rates as shown below (Fig. 3).

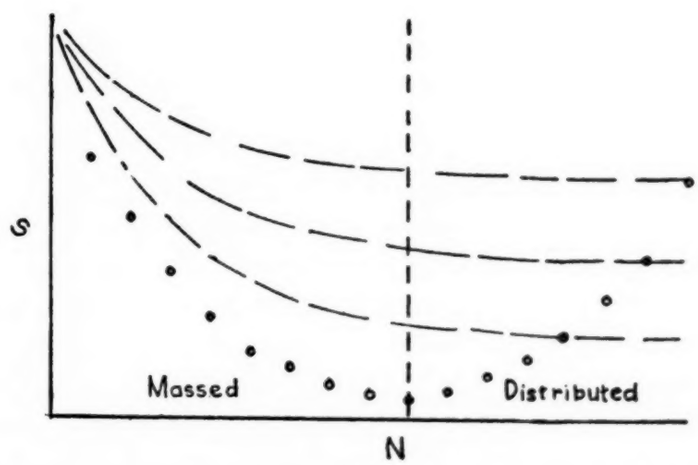

FIG. 3. Magnitude of a stimulus trace of constant t' under conditions of distributing of trials following a period of massing trials

Stating the implication above in terms of a conditioning experiment, it might be held that if acquisition is with massed trials and extinction with distributed trials, extinction will be more rapid with

distributed trials. As in the earlier instance, extinction will be carried out with a generalized stimulus and hence extinction will be more rapid. There are two factors which operate against the implication. First, with distribution of trials, the magnitudes of *s* which appear will have had some reinforcement. Second, it is known that with an established response, increasing the intensity of the conditioned stimulus increases the excitatory tendency of the conditioned response. The magnitudes of *s* appearing with distributed trials would be increased magnitudes. These two factors would tend to offset the operation of the generalization factor.

Purpose

The purpose of the present experiment was to test the implications of the theory of trace conditioning discussed above. These implications may be repeated now, summarily.

1. *The relation of the rate of application of the conditioned stimulus to the rate of extinction of a trace conditioned response acquired under conditions of distribution of the acquisition trials*

The implication drawn from the theory states that with massing of the extinction trials, in the case of a trace conditioned response acquired with distributed trials, extinction will proceed at a more rapid rate than when extinction trials are distributed. To test this, groups trained with distributed trials were split and half were extinguished with massed trials and half with distributed trials.

2. *The relation of the rate of application of the conditioned stimulus to the rate of extinction of a trace conditioned response acquired under conditions of massing of the acquisition trials*

The theory implies that a tendency exists for a response acquired under massing of the training trials to extinguish more rapidly with distributed extinction trials than with massed trials. If was noted, however, that this tendency was counteracted by certain other factors. The result of this interaction was held to be such that less difference between the extinction curves for a response acquired with massed trials would be observed than in the case of a response acquired with distributed trials. To test this implication, groups trained with massed trials were split and half were extinguished with massed and half with distributed extinction trials.

Procedure

The apparatus and the procedure for setting up the conditioned response have been described in the previous paper (11). The response used was eyelid closure, the conditioned stimulus being a click and the unconditioned stimulus a puff of air directed against the cornea.

Sixty-seven human adults were used as *Ss* in the experiment, approximately half of whom were trained with massed acquisition trials and half with distributed trials. Each of these two main groups was divided into four subgroups of 9–10 *Ss* whose training differed in terms of the time interval between the conditioned and unconditioned stimulus. These subgroups were split up once again in the extinction series, half being extinguished with massed trials and half with distributed trials.

The distributed group.—There were four intervals between conditioned and unconditioned stimulus used in this group, namely 250, 450, 1150 and 2250 msc. Ninety reinforced trials, with intervals between trials of 1–2 min., were given in four sessions. Twenty-five reinforced trials were given in each of the first three sessions, and 15 reinforced trials and 25 extinction trials in the final session. Approximately two min. intervened between the last training trial and the first extinction trial. In the extinction series, the interval between trials for the distributed extinction group was identical with that used in acquisition; that for the massed extinction group was 10–20 sec.

The massed group.—This group was divided as above, the same number of reinforced and extinction trials being employed. The same intervals between conditioned and unconditioned stimulus were used as with the distributed acquisition group save that there was no group corresponding to the 2250 msc. group. Each of the three subgroups was divided for extinction, and extinguished under conditions identical with those for the distributed group. We may summarize these conditions schematically.

Acquisition	Extinction
Distributed (4 groups)	Massed (four groups)
	Distributed (four groups)
Massed (3 groups)	Massed (3 groups)
	Distributed (3 groups)

Results

The results for both main extinction groups are presented below in tabular and graphic form. Table I contains data for groups trained with distributed trials, Table II that for groups trained with massed trials. Frequency of response during extinction is given in

TABLE I

Frequency of Extinction Responses in Mean Percents for Successive Blocks of 5 Trials When Acquisition has been Effected with Distributed Trials and Extinction with Massed or Distributed Trials

Interval, CS–UCS	250 msc.		450 msc.		1150 msc.		2250 msc.	
Extinction trials	*D*	*M*	*D*	*M*	*D*	*M*	*D*	*M*
0	86	50	100	96	75	66	32	30
1– 5	64	56	88	48	70	44	32	32
6–10	52	32	56	20	55	20	32	32
11–15	32	20	52	8	70	16	48	20
16–20	36	20	52	8	70	8	20	16
21–25	32	16	50	0	70	8	20	16
N =	5	5	5	5	4	5	5	5

O = Mean percent conditioned responses for last 10 training trials
M = Massed
D = Distributed

TABLE II

FREQUENCY OF EXTINCTION RESPONSES IN MEAN PERCENTS FOR SUCCESSIVE BLOCKS OF 5 TRIALS WHEN ACQUISITION HAS BEEN EFFECTED WITH MASSED TRIALS AND EXTINCTION WITH MASSED OR DISTRIBUTED TRIALS

Interval, CS–UCS	250 msc.		450 msc.		1150 msc.	
Extinction trials	*D*	*M*	*D*	*M*	*D*	*M*
0	56	86	90	68	47	50
1– 5	76	72	45	60	40	32
6–10	40	32	24	32	12	60
11–15	32	40	32	28	32	60
16–20	40	32	24	44	16	44
21–25	36	32	28	28	8	40
N =	5	5	4	5	4	5

O = Mean percent conditioned responses for last 10 training trials
M = Massed
D = Distributed

mean percent response per five trial block. Mean percent response for last 10 training trials is given for reference.

DISCUSSION OF RESULTS

The distributed acquisition group.—Extinction curves for each of the four interval groups under this main group are shown in Fig. 4. The plots are in terms of blocks of five trials, which with five *Ss* per group gives a total of 25 trials per point. The curves for extinction under massing and under distribution of the extinction trials are plotted separately for each interval. It will be observed that the curves for *Ss* extinguished with distributed trials fall more slowly and have lower limits than those for *Ss* extinguished with massed trials. The assignment of *Ss* to the subgroups in the 250 msc. extinction groups did not give groups which were approximately equal in mean percent response for the last 10 conditioning trials, upon which the point on the y axis at $x = 0$ is based. Upon the basis of mean percent response during the training series the difference between the two groups is only 8 percent and this difference is barely significant at the 30 percent level of confidence. The difference between mean percent response during the extinction series for the two extinction groups for this interval, however, is significant at the 5 percent level. The differences observed at the 450 msc. and 1150 msc. intervals are very marked. The difference at the 2250 msc. interval is less marked, but the curve for the distributed extinction group is above that for the massed extinction group at every point. The difference between mean percent response during the extinction

series in favor of the distributed extinction group is significant at the 10 percent level of confidence. These results are consistent with those reported by Pavlov (6) and of other Russian experimenters whose results have been reviewed by Razran (10).

Extinction responses in blocks of five have been tabled for each interval group (Table I).

The massed acquisition group.—Extinction curves for the interval groups under this main group have been plotted as for the distributed

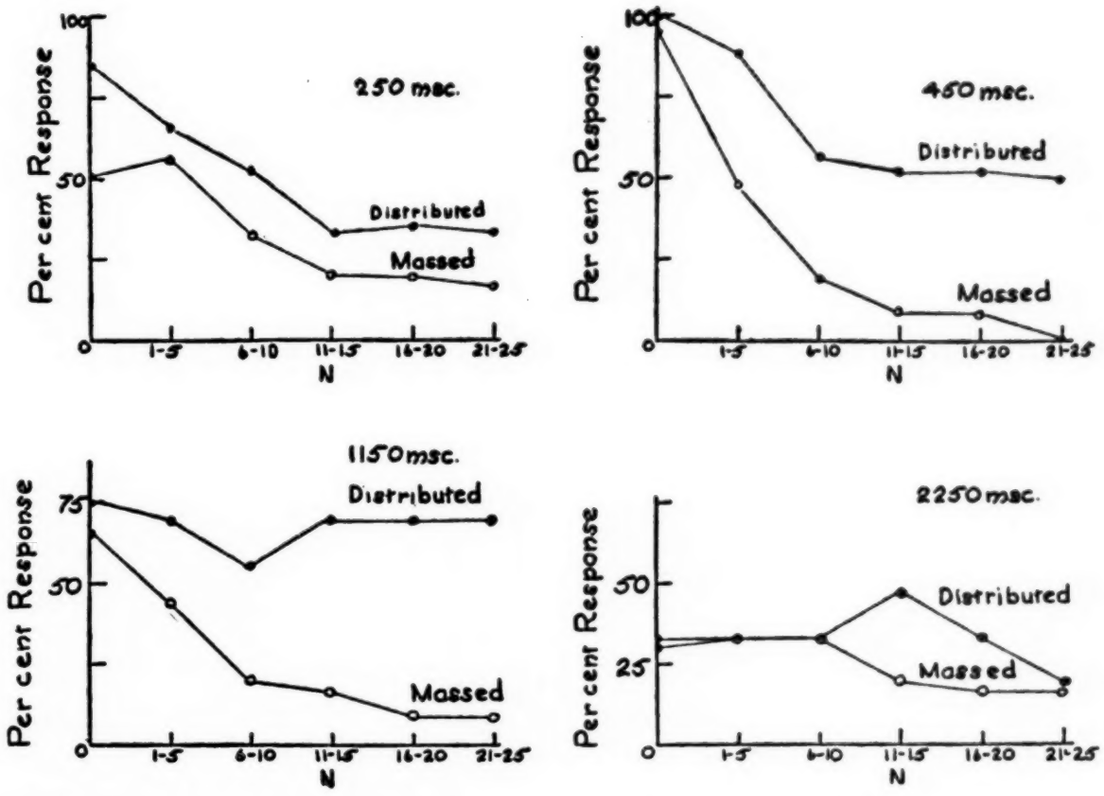

FIG. 4. Extinction curves for groups trained with distributed trials and extinguished with massed and distributed trials

acquisition group (Fig. 5). It can be seen at a glance that there is no difference between the massed and distributed extinction curves for each interval group save in the case of the 1150 msec. group. As in the case of the 250 msec. group conditioned with distributed trials, the 250 msec. group in the present case was divided into subgroups which were unequal on the basis of the last 10 training trials. The groups were equal, however, on the basis of mean percent response for the total training series. The extinction curve for the massed extinction group at the 1150 msec. interval is above that of the distributed extinction curve. The differences between mean percent response during the total extinction series is barely significant at the 30 percent level.

The results for the massed extinction group are presented in Table II.

Massing vs. distribution of extinction trials when acquisition has been with distributed trials.—The implication drawn from the theory stated that when acquisition had been with distributed trials, extinction would be facilitated by massing and retarded by distribution of the extinction trials. This followed from the fact that with distribution there would be a tendency for the same magnitude of *s* to be presented in the extinction trials as was reinforced in the acquisition trials. On the other hand, with massing of the extinction

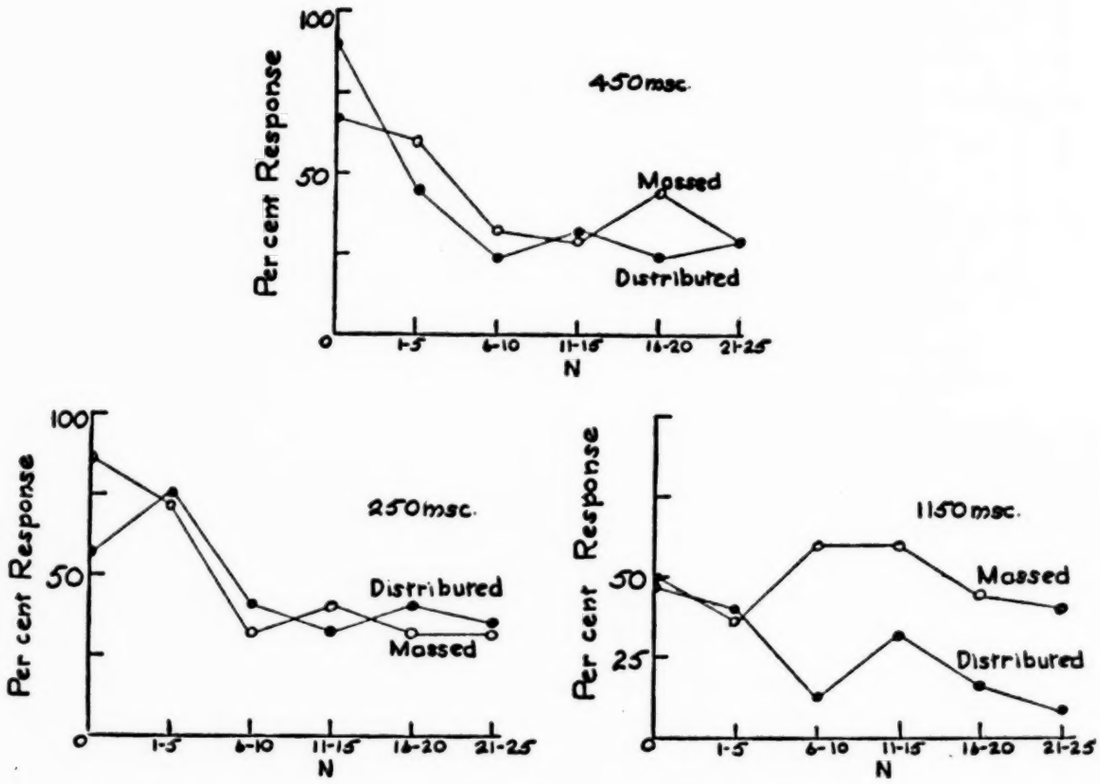

FIG. 5. Extinction curves for groups trained with massed trials and extinguished with massed and distributed trials

trials there would be a tendency for the magnitude of *s* to decrease rapidly and the extinction would involve magnitudes of *s* which constituted generalizations from the magnitude which had been reinforced.

Extinction curves for the four distributed groups show that this implication has been completely confirmed with all groups (Fig. 4). The differences in the 450 msc. and 1150 msc. groups are very striking. It will be noted that the curve for the 250 msc. distributed extinction group begins much higher than that for the massed extinction group. It is unfortunate that, due to the necessity of developing records before conditioning could be determined, the

groups could not be equated. What occurred here was simply a bad sample of the last 10 trials. To test this assumption of variation in the last 10 trials only and not in the total trials, mean percent response for 90 trials was calculated. This turned out to be 52.4 for the distributed group and 45 for the massed group. The difference, however, barely attains significance at the 30 percent level of confidence, t for eight d.f. being 1.155. The t for the difference between mean percent response during the extinction series is significant beyond the 10 percent level, being 2.1492 for eight d.f. Since the differences between the extinction curves for the 2250 groups were not as marked as with the shorter intervals, even though the curve for the distributed group was above that for the massed group throughout the trials, and there is obviously a greater area under the distributed curve, this difference was tested. The t turns out to be 2.1311, which is significant beyond the 10 percent level for eight d.f.

Massing vs. distribution of extinction trials when acquisition has been with massed trials.—The implication from the theory is that with distribution there will be a tendency for extinction to be more rapid than with massed trials, but that this tendency will be counteracted by the operation of other factors. The chief factor operating to limit the tendency is held to be that of increased excitatory potential, due to the fact that the magnitude of the trace is increasing. If we examine the extinction curves for the 450 msc. and the 250 msc. groups we see that actually there is no real difference in extinction (Fig. 5). On the basis of the last 10 training trials samples of different mean frequencies were obtained. In the case of the 250 msc. group a comparison of the percents of response for 90 training trials reveals that the groups were practically identical, the mean for the distributed extinction group being 44.8 percent and for the massed extinction group 42 percent. The mean percent response during the extinction series was 44.8 percent for the distributed extinction group and 41.6 percent for the massed extinction group. In the case of the 450 msc. group the differences between the two extinction groups in mean percent response during acquisition was greater, being 50.5 percent for the distributed extinction group and 35.0 percent for the massed extinction group. The t for the difference is 1.3337 which is significant at the 30 percent level. The percent response during extinction was 37 percent for the distributed extinction group and 38.4 percent for the massed extinction group.

Implication of the Present Results for Theories of Extinction

Since such a considerable controversy has raged around the problem of experimental extinction, it may be well to consider the implications of the results discussed above for theories of extinction,

and of learning generally. Pavlov's (**6**) theory of extinction implied that extinction occurs through the development of internal inhibition, conceived of as a central state which developed whenever a response was evoked. Each evocation of a response adds its quantum of inhibition, until the concentration of inhibition in any response system becomes sufficient to make for a decrement in, or a complete blocking of, the response. The effect of reinforcement is to retard the development of internal inhibition. During extinction, inhibition develops more rapidly because of the absence of the restrictive power of reinforcement. Inhibition is assigned several properties, one of which is dissipation in time. The rate of dissipation is held to be greater for inhibition than for excitation. The inhibition which is developing rapidly in extinction is also dissipating at the same time, the total amount of inhibition present at any given instant being a joint function of the rate of increment and the rate of dissipation. The implication which follows immediately from this hypothesis is that extinction will proceed more rapidly with massed extinction trials than with distributed trials. Pavlov stated this to be the case.

The Pavlovian theory of extinction has been attacked by such writers as Guthrie (**1, 2**) and Wendt (**12**), who offer in its place what is usually termed an interference theory. Under this theory extinction occurs because of the conditioning of interferring responses to the conditioned stimulus. Extinction is thus simply learning, and hence will exhibit the characteristics of learning. The implication which follows is that curves of extinction should show the same characteristics as curves of acquisition, and, since it is a generally attested fact that distribution facilitates acquisition, it should facilitate extinction, and massing should retard extinction, as it retards acquisition. Pavlov held that the converse of this was true, that massing facilitated extinction and distribution retarded it.

The evidence on the relation of rate of presentation of the conditioned stimulus and extinction which has come from American laboratories is meager and contradictory. The Russian work is said to be consistent with Pavlov's position (**10**). Unfortunately, our knowledge of that work is only secondhand. If the Russian data do show that massing facilitates extinction they are consistent with the results of the present experiment. Most of the conditioning done in Russian laboratories is done with extreme distribution of the acquisition trials. What has been called distribution in the present study would be considered extreme massing among Russian experimenters. One or two trials per day, separated by several minutes or even several hours, was the usual procedure for conditioning in Pavlov's laboratory. We should expect that when these responses

were extinguished with massed trials they would show a rapid decrement.

When an attempt is made to relate our present findings to other studies which report extinction the difficulty which is immediately encountered is that most experimenters have failed to report the intervals between trials during acquisition, and even during extinction. This is true of even such studies as those of Porter which were directly concerned with the relation of the interval between extinction trials and number of trials to extinction.

Hilgard and Marquis (**13**) report a study with four dogs. The animals were conditioned through four sessions of 50 trials each, and were given 60 extinction trials immediately following the end of the acquisition trials. The time between all trials was 20–40 sec., which would be termed massed presentation in the present discussion. Extinction was carried out, therefore, under the same conditions as held during acquisition. Percent response for the last 50 training trials was 89 percent, while the estimated frequency for the first 25 trials in the extinction series was something above 80 percent. The amount of extinction was exceedingly small for 25 trials when extinction was carried out under the same conditions holding during the acquisition series.

One dog from the above experiment was extinguished a second time. Four months following establishment of the response, during which time the response had been tested and reinforced, the response was reëstablished with 10 reinforced trials. This was followed by 10 extinction trials every second day for 20 days. On the 20th day, 60 additional extinction trials were presented. A response kept at a high level through a few trials spaced throughout a period of four months would apparently qualify as a response acquired with distributed trials. It is interesting to note that the response showed practically no extinction throughout 110 trials. During the 60 massed trials the response showed a marked decrement.

Youtz (**13**) reports a study with the Skinner box which is difficult to interpret but which may be related to the present results. The bar was introduced into the box and the animals determined their own intervals between trials. This ranged from 3.7 to 1.5 min. as the experiment proceeded, these values being mean values. Some animals took longer than others so that time between trials varied for each animal. The correlation for time between trials and number of extinction responses was .69. Unfortunately we have no way of knowing whether the animals who took longer to press the bar during acquisition also took longer to press it during extinction. If such was the case the results of this study are in line with the present results.

Porter has carried out several studies on the problem of the relation of rate of extinction to the spacing of extinction trials (**7**, **8**, **9**). In one of these (**9**) he conditioned the eyelid response in 39 *Ss*, giving 75 reinforcements with an interval between conditioned and unconditioned stimulus of 500 msc. The interval between trials is not given, but considering the number of trials and the commonly used intervals in eyelid conditioning work, we will assume it was relatively short, 15–25 sec. Following training the *Ss* were extinguished with varying intervals between trials, namely, 10, 20, 40, 80 and 180 sec. Porter reported no significant difference between trials to extinction to a criterion between any group.

Let us examine these results in the light of those from the present study. We have assumed the rate of presentation of the conditioned stimulus to be three per min., i.e., 20 sec. between trials. From our own results we would predict that extinction with an interval of 20 sec. between trials would require more trials to reach an extinction criterion than with any other interval, since this was the rate of presentation of the conditioned stimulus during acquisition. As the interval was increased beyond 20 sec. or decreased below 20 sec., trials to extinction would decrease. An examination of Porter's extinction data shows this to be the case, the most rapid extinction occurring when the intertrial period was longest. These results are consistent with those reported here.

It should be noted at this point that the results reported in our own study are in agreement with those reported by Pavlov, in the case of extinction groups trained during the acquisition period with distributed trials. The present reported results for extinction with groups trained with massed trials cannot be compared with any results obtained by Pavlov under comparable conditions since he did not report the results of such an investigation. It is unlikely that any such experimentation was carried out by Pavlov or any of his associates. The usual practice in the Pavlovian laboratory was to employ distribution of trials in the training series. The implication which would seem to follow from Pavlov's theory is that massing of extinction trials would make for more rapid extinction than distribution of extinction trials no matter what the conditions as to distribution of trials during acquisition. The results reported here offer a negative confirmation of this implication.

Summary

The results of the present study may be summarized as follows:

1. Four groups of *Ss* trained with distributed acquisition trials were divided for extinction, half being extinguished with distributed

and half with massed extinction trials. It was found that massing facilitated extinction.

2. Three groups of *S*s trained with massed acquisition trials were divided for extinction, half being extinguished with distributed and half with massed extinction trials. No consistent differences between groups extinguished with massed extinction trials and groups extinguished with distributed extinction trials was observed.

3. It was shown that these results above were in agreement with implication drawn from a theory of trace conditioning.

4. The results of the present experiment were shown to support in part the Pavlovian theory of extinction. They were shown to offer negative confirmation of the implication from the theory which states that massing of extinction trials will always facilitate extinction.

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DRIVE INTERACTION: I. LEARNING AS A FUNCTION OF THE SIMULTANEOUS PRESENCE OF THE HUNGER AND THIRST DRIVES

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INTRODUCTION

Psychological investigators have recently been much concerned with the problem of stimulus interaction. A good part of this interest can be attributed to the writings of the Gestalt psychologists who have investigated this problem in the field of perception. However, like most other experimental phenomena, this area of research has been subjected to the empirical probings of other groups of theorists. Thus, in the field of conditioning we find that Pavlov was actively interested in similar phenomena and at the present time configurational learning is a central problem for the conditioned response theorist (**6**).

Because external stimuli are more amenable to control and manipulation than are internal drives, the studies bearing upon stimulus interaction have been largely restricted to experiments involving interaction between external stimuli. However, the great importance of the role of drive in behavior changes has been clearly recognized by most psychological theorists. It is therefore essential, if we aspire to formulate a more inclusive behavior theory, to ascertain the laws of drive interaction.

The history of studies concerned with drive interaction is brief. Emphasis on the importance of a complex motivating state appeared initially in the writings of the psychoanalysts. The concepts of 'libido' and 'will to power' as introduced by the members of this school of thought, are more or less a conglomeration of many specific drives. However, the precise relationships involved in these concepts have never been formulated in such a manner as to render them amenable to experimental investigation.

In addition to theoretical discussions, several experiments have been performed which provide some enlightenment, although little systematic knowledge as to the mechanisms of drive interaction.

[1] This article is part of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Department of Psychology, in the Graduate College of the State University of Iowa. The writer wishes to acknowledge the valuable advice and assistance of Professor Kenneth W. Spence during the progress of this work.

The question whether animals are capable of acquiring differential reactions based solely on internal cues was answered in the affirmative by studies of Hull (**5**) and Leeper (**9**). Their albino rat subjects learned to take one path to food when hungry, another which led to water when thirsty. The present writer (**7**) in an unpublished experiment discovered that rats could learn to discriminate between hunger and thirst drives even when they were present simultaneously during the learning trials. In this experiment the animals, both hungry and thirsty during the training series, were rewarded on one side of the T-maze with food, and on the other side with water. When motivated on test days for only one of these goal objects (i.e. when either hungry or thirsty), the subjects chose the appropriate side with a considerable degree of accuracy, as evidenced by 85 percent correct choices.

Elliot (**1**) compared the speed of learning a 14 unit multiple T-maze by three groups of white rats which were motivated for both food and water. One group (E) was both very hungry and very thirsty, a second group (F) was very hungry and only slightly thirsty, and a third group (G) was slightly hungry and very thirsty. Over a nine-day period of training, group E showed a definite advantage in terms of errors over the other two groups whose performances were about the same. Elliot concluded that the data suggests that the presence of two 'strong' drives facilitates acquisition of maze proficiency. Unfortunately the data are not conclusive so far as rate of learning is concerned, for group E showed an initial superiority of slightly less than one error and increased this superiority only slightly in the nine days of training.

The purpose of the present paper is to report two experiments bearing upon the problem of drive interaction.

Experiment I

1. Statement of the problem

According to Hull's (**6**) recent formulation of behavior theory the presence of additional drives is assumed to facilitate learning. Elliot's results (**1**) suggest that the presence of two 'strong' drives aids in the acquisition of maze proficiency. In his experiment the animals of the very thirsty, very hungry group (E) were deprived of water for only eight hours. Following the removal of the water bottles from the home cages, the rats were given a small pellet of food, which in all probability increased their thirst. The purpose of this experiment was to determine whether a thirst drive of a still greater intensity would facilitate the acquisition of a simple T-maze discrimination, in which food served as the reward.

2. *Experimental procedure*

The *Ss* for this experiment were 32 male albino rats from the colony maintained by the Psychology Department of the State University of Iowa. Their ages ranged from 106 to 138 days and they all had had previous experience in a Skinner box experiment.

A single choice T-maze, the floor plans and dimensions of which are shown in Fig. 1, was used. Walls and floors were constructed of pine board, 5½ in. by ¾ in., so that the width of the maze path was 4 in. The maze was covered with hardware cloth. The doors were of sheet metal lined with felt, so that when manipulated in a vertical direction by means of strings, they were practically noiseless. The experimenter was able to control all doors from behind a screen which was 61-in. high by 24-in. wide. Curtains were hung before each goal box in order to make it impossible for the animal to see what was present in the goal box prior to its choice. Both goal boxes contained sheet metal panels into which drinking orifices, similar to ones the animals were accustomed to drink from in their home cages, could be inserted. These panels could be hidden by placing wooden guards in front of them. The walls and floors of the entire maze were painted white.

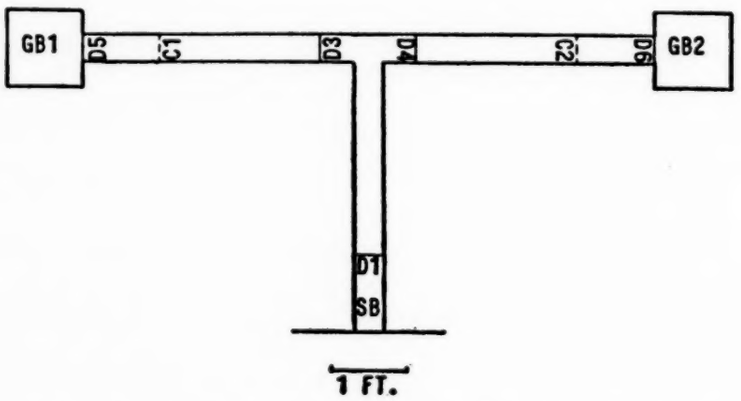

FIG. 1. Ground plan of apparatus. S. B.—Starting Box; D1, D2, D3, D4, D5—Doors; C1, C2—Curtains; GB1, GB2—Goal Boxes.

The *Ss* were tested for position habit by allowing them three free choices. It was decided beforehand to discard any animal that chose the same side three times. Three did so and therefore were discarded before the training series began. The rats were divided into two groups of 16 *Ss*, each group having different motivating conditions during the learning trials. The division was based on the records of the test trials for position habit. Group H (hungry) was deprived of food for 22 hours while Group H & T (hungry and thirsty) was deprived of both food and water for the same period of time (22 hours). Food, in the form of 10 large pellets of Purina Dog Chow, was present in one of the goal boxes, while nothing was placed in the other. Whether food, for any animal, was placed in the right or left goal box was determined by the three position test trials. Food was always placed in the goal box on the side which the animal chose only once during the three trials. Therefore all animals had to learn to go to the side they preferred least in the original three test trials.

The specific details of the feeding schedule for Group H were as follows: The animals were given one and a half pellets of dog chow (nine gm.) approximately 15 min. after its experimental session. The time from complete consumption of this food to the beginning of the next day's trials was approximately 22 hours. The water bottles for Group H were filled and always available. Group H & T had the same regimen except that their water bottle was removed after finishing one pellet of food. The rats of Group H & T were, however, permitted to finish drinking before the water bottle was removed. The remaining half pellet was then given. This group (H & T) therefore had 22 hours of deprivation of both food and water. The thirst drive was further increased by giving the last third of the animal's ration in the absence of water.

Each *S* was given three trials per day until the criterion of learning, 12 successive correct trials (four perfect days), was attained. When the animals chose the correct side they were allowed to eat for 20 sec.; when they chose the wrong side they were required to remain in the empty goal box for an equivalent period. Both water panels were covered by wooden guards. At least 15 min. elapsed between successive trials of the same *S*.

3. *Results and discussion*

Table I indicates the mean number of errors for each group (H and H & T) to reach the criterion of learning and the standard deviations of these measures.

TABLE I

MEAN NUMBER OF ERRORS, AND THEIR σdis., TO THE CRITERION OF LEARNING

Group	Mean	σ distribution
H	2.31	1.96
H & T	3.69	2.50

It is evident that the distributions are highly skewed since the lowest possible number of errors, zero, is less than 1.5 sigma units from the mean in both groups. The range of errors for Group H was from zero to six, while for Group H & T it was from zero to eight. It is not legitimate to use the classical method of evaluating the reliability of a difference between these two means, for the means of exponential or highly skewed distributions do not arrange themselves normally. However, Festinger (3) has recently devised a test of significance for differences between means from such skewed populations.

With this technique one obtains the ratio between the two means, the larger of the two means being the numerator. The obtained ratio equals F and in order to evaluate the results, reference must be made to an F table. The degrees of freedom for each mean equals $2np$, where n equals the number of cases and p equals the mean squared divided by the variance ($p = M^2/\sigma^2$). In the case of the present data the ratio is 1.595; the number of degrees of freedom for the H & T group is 70, while for Group H it is 45. The difference between the means is significant at the 5 percent level of confidence[2], and so we may reasonably reject the hypothesis that the obtained discrepancy between the two means can be attributed entirely to the random selection of the animals.

This experiment contrasted the learning of two groups of animals both of which were motivated by a 22-hour hunger drive, but in one of which there was a coexistent thirst drive of a relatively intense magnitude. The results revealed that the additional thirst drive retarded the acquisition of the correct response. It would appear from these findings that the presence of an additional drive does not always facilitate learning. It should be added that the thirst drive in no way inhibited the actual eating response of the H & T Group. Upon their entrance into the goal box they seized the food and ate it

[2] Ascertained from graphical interpolation between degrees of freedom from Snedecors' table of F (10).

as readily as the H Group. Another indication of this is the fact that there was no significant difference between the median latencies (time elapsing between the exit from the starting box to the entrance into the goal box) for the two groups on their last three criterion trials.

Experiment II

1. *Statement of the problem*

The first experiment indicated that the learning of a simple spatial discrimination, in which food served as a reward, is retarded when a strong thirst drive is concomitantly present with the hunger drive. However, the results of this experiment do not preclude the possibility that at certain weaker intensities the presence of the thirst drive might facilitate such learning. As a matter of fact Elliot's data (1) suggest this possibility. Since Elliot worked with the same interacting drive (thirst) of a weaker magnitude, we are confronted with the possibility that an additional drive has differential effects at various intensities. The purpose of this experiment was to vary the strength of the thirst drive from zero to 22 hours of water deprivation and thus ascertain the nature of the relationship between rate of learning and the strength of a coexisting drive.

2. *Experimental procedure*

Subjects

The *Ss* for this experiment were 125 white rats from the department's colony, divided into five groups on the basis of age and weight. The mean weights of the different groups at the start of the experiment ranged from 200.6 gm. to 203.8 gm., the mean ages from 116.0 to 118.4 days. The range of the mean weight loss for the six day experiment was from 16.9 gm. to 20.0 gm.

Apparatus

Because the T-maze of the first experiment failed to provide a wide range of learning scores, it was decided to use a learning situation that would not suffer from such a limitation. The apparatus decided upon was a modified Skinner box, similar in design to that used by Ellson (2) Williams (15), and Perin (11). The compartment into which the animal was placed measured one foot in each of its dimensions. On one wall of the compartment was a brass panel containing an aperture into which a horizontal bar, 55 mm. in length, could be inserted. When the bar was withdrawn a sliding shutter automatically covered the aperture. The inserting and withdrawal of the bar were controlled by the movement of a lever fastened on the outside of the box.

A pressure of approximately 15 gm. applied by the rat would depress the bar, thereby closing a mercury-cup contact in series with an electromagnetic food release. This resulted in the release of one pellet of food from the food magazine. The pellet traveled through a glass tube in the back of the box into a metal food tray in front of the brass panel. The pellets, cylindrical in shape and weighing about .2 gm., were manufactured by the Purina Dog Chow Company. Except for their shape and size, they were the same as the larger pellets which constituted the daily diet of the colony.

The movement of the lever which controlled the insertion of the bar through the aperture automatically started a Springfield clock. When the bar was depressed by the animal the clock stopped and the latency of response in hundredths of a sec. was recorded by the experimenter. During extinction of the response, no pellets were placed in the food magazine and therefore the depressing response did not result in a pellet of food dropping into the food tray.

Connected to the removable metal floor of the Skinner box was a small three-sided wire cage, the open side of which was placed directly in front of the brass panel. The measurements of this restraining cage were 5 in. high and 2⅜ in. wide in the front, and 2¾ in. high and 2⅜ in, wide in the back.

Preliminary training

In order to reduce the emotionality of the animals and thereby reduce variability, certain pre-training procedures were used. The animals were handled until all squealing and wiggling disappeared. Since the individual *S*s varied in their emotionality, some received more handling than others. But the criteria for adjustment and readiness for experimentation were certain behavioral manifestations—pliability, lack of squealing, failure to avoid the hand when it is placed in the home cage, absence of defecation and micturition when handled, etc.

After the animals reached the proper stage of emotional adjustment, they received two training periods on successive days to promote adjustment to the Skinner box situation. They were allowed to feed in the apparatus until they had consumed four gm. of small pellets. Then they were removed to feeding cages where they were fed the remainder (five gm.) of their daily rations. Water was always present in their feeding and home cages. The day following the second training period the *S*s were conditioned to the click of the food-releasing mechanism. Three pellets were present in the food tray when the rat was placed in the restraining cage of the box. As the third pellet was being consumed the experimenter released another pellet from the food magazine by depressing a small button fastened to the outside of the box. Twenty pellets were released in such a manner. Following the training session of this day, the motivational conditions of the various animals were manipulated in the manner described below.

Method of controlling motivation

The motivation of the five groups were as follows.[3]

Group T- 0	22 hours hunger, 0 hours thirst
Group T- 3	22 hours hunger, 3 hours thirst
Group T- 6	22 hours hunger, 6 hours thirst
Group T-12	22 hours hunger, 12 hours thirst
Group T-22	22 hours hunger, 22 hours thirst

The different drive states were controlled by the following experimental operations:

Group T-0. At the appropriate time (22½ hours prior to its experimental session) the *S* was placed in the feeding cage, through which the orifice of the drinking bottle was placed. It was allowed to drink for approximately five min. and then the water bottle was removed. This period of five min. provided sufficient time for the animal to satisfy its thirst drive. The water bottle was never removed while the animal was drinking. Following this the *S* was given one large pellet of food (six gm.) which it consumed in approximately 25 min. A half hour before its experimental session (21½ hours after the termination of the eating) each *S* received water and was permitted to drink until it was placed in the experimental situation. This group is referred to as zero thirst group because water was made available to the animals immediately prior to their experimental session.

If an *S* of this group was to be tested in the Skinner box at 10 A.M. Monday, it would be placed in the feeding cage at 11:30 A.M. Sunday, at which time the orifice of the water bottle would be made available. At approximately 11:35 A.M. the water bottle would be removed and a large pellet of food would be given. At 9:30 A.M. Monday, the water bottle would be presented and at 10 A.M. the animal would be placed in the experimental situation.

Groups T-3, T-6, and T-12. The operations controlling the motivational states of the animals in these groups were similar to those used for Group T-0, except that the water bottle was reinserted into the cage 3½, 6½, or 12½ hours prior to their daily experimental session and remained there for a half hour.

Group T-22. Twenty-two and a half hours prior to its experimental session each member of this group was given one large pellet of food and the orifice of the drinking bottle was inserted

[3] Because all groups had the same hunger drive, reference will be made to them in terms of their thirst drive only. It should be remembered that all groups in this experiment had 22 hours of food deprivation.

into the feeding cage. The water bottle was removed five min. *after* the *S*s had finished their rations. The feeding and drinking required approximately 30 min.

Method in Learning Problem and Extinction Series

The experiment proper involved three sessions on successive days. On the day (Day 1) following the adaptation to the click of the food release mechanism, the animals learned the bar depressing response. On the first occasion a small amount of moist food was placed on the bar and in attempting to remove the food the rat usually depressed the bar, thereby releasing the food pellet. The first counted response occurred when the rat started eating the food within five sec. following bar depression. This day's trials consisted of 15 reinforcements beginning from the first counted response. On the second day (Day 2) 15 additional reinforcements were given. The animals, therefore, received 30 reinforcements during Days 1 and 2. On the third day the bar depressing habit was extinguished, i.e., no food was delivered following the response of bar-depressing. The specific operations of this procedure will be described in the succeeding paragraph.

There were two radical differences in our procedure as compared with the Skinner box methodologies utilized by Perin (11) and Williams (15).

(1) The animals were not permitted complete freedom of the area within the box, but they were restricted to the confines of the restraining cage described in the section on apparatus. Walker (13) in an unpublished article found confinement to the small cage as compared with the large area greatly reduced the variability of the extinction scores.

(2) The latency of the bar-depressing response was measured. During the acquisition trials, as soon as the animal depressed the bar it was withdrawn. After the animal had finished its food and was facing the stimulus situation (the brass panel which included the aperture through which the bar was inserted and withdrawn) the bar was reinserted after the lapse of varying time intervals. This was done in order to avoid temporal conditioning. The order of this variation was as follows: 9, 15, 6, 3, 12, 12, 3, 6, 15, and 9 sec. on successive trials, after which the order repeated itself. Since there were 30 reinforcements during the two-day training series, the order of time intervals from the termination of the eating response to the insertion of the bar repeated itself three times. During the extinction series (no food delivered) the bar was reinserted at varying time intervals (between 15 and 35 sec.) after the bar had been depressed. This order of variation was, in terms of sec., 20, 35, 25, 15, 30, 30, 15, 25, 35, and 20, and then the sequence was repeated. If the animal did not make a response during a 15-sec. period following the insertion of the bar, the bar was withdrawn and then after the appropriate time elapse reinserted. The criterion for extinction was the failure on the part of the animal to make a bar-depression response during three consecutive 15-sec. trial intervals. During acquisition and extinction the bar was never inserted unless the animal was facing the brass panel.[4]

Results and their statistical evaluation

The design of this experiment lends itself to a simple analysis of variance type of statistical treatment. However, since two assumptions of analysis of variance are (1) homogeneity of variance from group to group and (2) normality of the parent population from which the samples are drawn, it is first necessary to ascertain whether these two conditions are satisfied. If not, it is not legitimate to utilize this technique.

An examination of Table II, which presents the mean number of responses for each group to reach extinction and the variance of

[4] It was quite common during the extinction series for the animal to turn away from the brass panel. In order to make the animal turn back towards the panel the bar was rapidly inserted and withdrawn. The slight noise arising from the movement usually resulted in the animals' turning around to face the panel.

TABLE II

MEAN NUMBER OF RESPONSES TO REACH THE CRITERION OF EXTINCTION

Group	Mean	Variance
T-0	21.36	147.57
T-3	25.56	239.67
T-6	25.16	237.89
T-12	32.92	489.41
T-22	18.88	107.03

these scores, reveals that these data do not meet the requirements of analysis of variance. The largest variance is more than four and a half times as great as the smallest, which seriously violates the assumption of homogeneity of variance.

Lindquist (**10**) has indicated that the assumptions of homogeneity of variance and normality of parent population are not crucial, in the sense that slight deviations from them do not invalidate conclusions drawn concerning the means of the various groups. However, in the present instance the assumptions are apparently severely violated and since nothing is known as to the effects of such extensive deviations, any interpretation of the results of the analysis would be seriously impaired. In such a dilemma one has the choice of two alternative procedures. One can abandon this particular type of statistical treatment and seek some other which the data of the experiment do satisfy. Or one may attempt to discover some new manner of defining the observed phenomena (i.e., new measures) which will satisfy the necessary statistical assumptions. Both procedures have been followed in the treatment of the present data. We shall deal first with the method which involved a redefinition of the response measures.

In place of our first score which was obtained by simply counting the number of trials taken to reach extinction, a new measure was introduced. This new measure was $1000 \times \log_{10}$ of the old score, the constant 1000 being introduced merely for the purpose of avoiding decimals. There is considerable precedent for the use of such a logarithmic scale in measuring behavior, although the choice of descriptive units in science is in many cases a matter of expediency. Thus, Graham and Gagné (**4**) employed a logarithmic measure similar to the one proposed here because it provided a normal distribution of the latencies of their *S*s' responses.

Table III indicates the means and variances of the transformed scores.

An *F*-test between the most divergent variances indicates that this difference is not significant beyond the 5 percent level of confidence and therefore could be attributed to random selection. Since the assumption concerning homogeneity of variances is not appreci-

TABLE III

MEAN NUMBER OF RESPONSES (1000 × $\log_{10}$) TO THE CRITERION OF EXTINCTION

Group	Mean	Variance
T-0	1,270	52,098
T-3	1,315	93,655
T-6	1,335	57,792
T-12	1,448	58,589
T-22	1,209	64,918

ably violated, and since the skewness is reduced, any significance obtained between the two estimates of the population variance (transformed scores) can be attributed to variations of the means of the five different samples.

Analysis of the scores into two components resulted in an obtained F of 195,431.5/65,410 or 2.99. Since the error term was based on 120 degrees of freedom, while the variance between groups had four degrees of freedom, the F obtained is significant beyond the 5 percent level of confidence. The null hypothesis, namely that varying degrees of thirst have no effect upon the performance scores, is thus rejected.

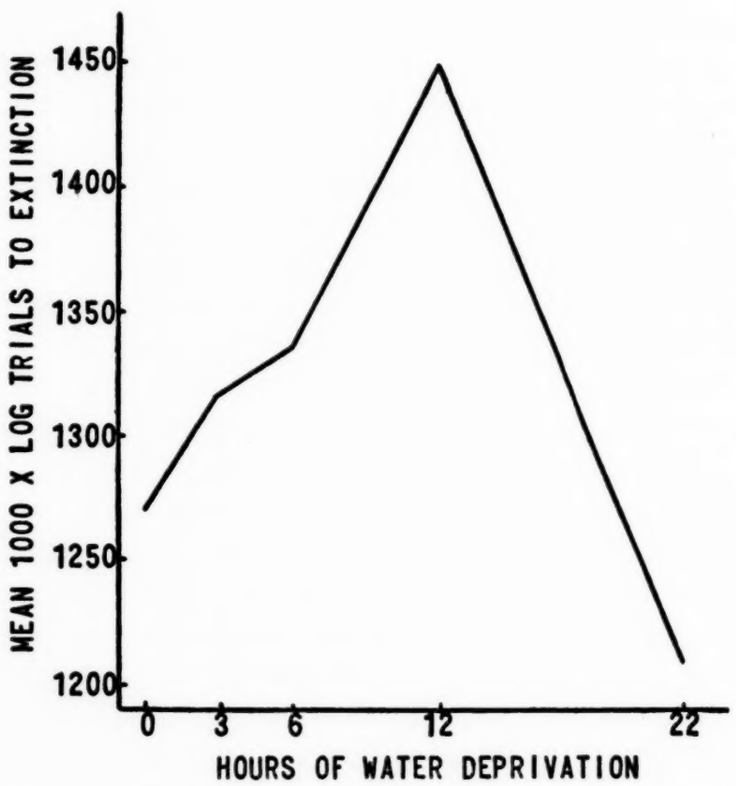

FIG. 2. Mean number of trials (1000 × $\log_{10}$) to the criterion of extinction for the five experimental groups

In order to test the significance of the differences between the highest central point of the ascertained relationship and the two low points on each end of our thirst dimension we can use the error

variance (65,410) as the best estimate of the variance within each group, since it is based on 120 degrees of freedom. The standard error of any of the means would be equal to $\sqrt{\frac{65,410}{25}}$ or 51.5. The estimated standard error of the difference would be equal to $\sqrt{2\sigma_M^2}$ or 72.33. The *t* of the difference between Groups T-0 and T-12 is 2.461, which is significant beyond the 2 percent level of confidence. The *t* of the difference between T-12 and T-22 is 3.304 which is significant beyond the 1 percent level of confidence. The 5 percent fiducial limit is 141.77, and therefore none of the other differences are significant at this level of confidence.

This *t*-test analysis contributes additional information to the general over-all analysis of variance into two components. The latter suggested that the presence of varying degrees of thirst drive with a constant degree of hunger has a differential effect upon the performance score. The test of significance between the extreme points is legitimate once the above has been indicated. It reveals some information about the nature of the functional relationship, namely that the response measure increases as the coexistent drive increases and then decreases after a certain point is reached. Fig. 2 shows this relationship more precisely. It reveals that the effect of increasing the thirst drive increases the resistance of the response to extinction up to a value of 12 hours of water deprivation. At the next experimental value, 22 hours of water deprivation, the extinction measure is much lower, being less than that at 0 hours of thirst. Further experimentation is necessary to ascertain precisely the locus of the peak of the curve. It obviously falls somewhere in the region between 6 and 22 hours of thirst.

The results of the statistical treatment with the use of the Festinger technique (**3**) are in essential agreement with those obtained from the analysis of variance of the transformed scores. The specific results can be found in the original thesis (**8**). The analysis revealed that two of the differences (T-12/T-22 and T-12/T-O) were significant at the 1 percent level of confidence, and two others (T-3/T-22 and T-6/T-22) were significant at the 5 percent level. This indicates that the differences between the means of the raw extinction scores cannot be attributed entirely to the random selection of the five groups.

A comparison of the median latencies of Groups T-12 and T-22 was made because these two groups revealed the largest difference in terms of extinction scores, and by adding *S*s of an experiment to be reported in the second paper of this series, it was possible to compare the data of 45 animals in each group.

There was little difference between the median latencies of Groups T-12 and T-22 for the first 15 trials, but for 13 of the last 15 trials the former group had a lower median latency than the latter group. This suggests that the time curve of the T-12 group reaches a lower asymptote. The experimental methodology of initially placing wet mash on the bar in order to instigate bar-directed behavior no doubt tends to minimize any difference between latency measures of different groups which might exist. Such a procedure should be avoided if the major concern is with a latency type of response measure, as was the case in a recent study by Perin (**12**).

Discussion of Results

The results of these experiments are of interest for the implications they carry for the recent formulations of behavior theory proposed by Hull (**6**). Beginning with the observed response variables Hull has formulated the following series of postulates.[5]

$$(1) \quad R = f({}_{S}\mathbf{E}_{R})$$

$$(2) \quad {}_{S}\mathbf{E}_{R} = f({}_{S}\mathbf{H}_{R}) \times f(\mathbf{D})$$

$$(3) \quad {}_{S}\mathbf{H}_{R} = f(N, T_{s}, T_{g}, M_{g})$$

$$(4) \quad \mathbf{D} = f(T_{d})$$

R = response measure, e.g., number of trials to extinction, amplitude of response, etc.;
${}_{S}E_{R}$ = excitatory potential, a theoretical construct defined in terms of ${}_{S}H_{R}$ and D;
${}_{S}H_{R}$ = habit strength, a theoretical construct defined as a certain function of four experimental variables;
N = number of reinforcements following the response to be learned,
T_{s} = the time the conditioned stimulus is acting before the occurrence of the response to be learned,
T_{g} = time of delay of attainment of goal object following response to be learned,
M_{g} = magnitude of the goal object,
D = drive strength defined as a function of T_{d};
T_{d} = time of deprivation of some goal object or goal objects.[6]

[5] The boldface symbolic constructs are intervening variables and therefore are not observable. It should be noted that they are ultimately defined in terms of those independent, manipulable variables which have been shown to play an important role in simple learning situations.

[6] Certain other factors (e.g., inhibition, ${}_{S}I_{R}$) enter into this theoretical framework but for the sake of simplicity they are omitted from the above discussion. This is possible because none of the known variables responsible for the strength of the inhibitory potential were different for the various drive groups of the present experiments.

In the present experiment [7] these constructs would be employed as follows. As the result of the training trials under the experimental conditions of magnitude and delay of reward a certain amount of habit strength to bar depressing would be developed. Under the particular drive conditions this would produce a certain excitatory or behavior potential to make the response of depressing the lever. The habit strength ($_sH_R$) and drive strength (D) are assumed to combine in a multiplicative manner to determine this behavior potential. The greater the behavior potential developed as the result of this training the greater will be the number of non-reinforced responses to reach the criterion of extinction.

As Hull's theory is now formulated, the variations in the behavior potentials (as measured by the number of trials to reach extinction) of the five groups would be a function of the various drive strengths at the time of extinction.[8] On the assumption of the multiplicative function (equation 2) our experimental curve (see Fig. 2) would mirror the change in this hypothetical drive strength (D) as a function of the time of deprivation of water. In this connection Hull would be required to modify somewhat his present postulate as to the effects of coexistent motivational states in the drive strength of the organism. In Chapter XIV of his recent book (**6**) Hull has postulated that the presence of additional drives should increase the strength of the excitatory potential. He has proposed the following equation[9] as representing this relationship:

$$(5) \quad {}_sE_R = {}_sH_R \times \frac{D' + \dot{D}}{M_d + \dot{D}},$$

where D' = the intensity of the drive being rewarded (hunger in the present experiment).

M_d = the maximum possible value of the drive being rewarded.[10]

$\dot{D}$ = the strength of the coexistent drive (thirst in the present experiment).

As $\dot{D}$ increases, the fraction $\frac{D' + \dot{D}}{M_d + \dot{D}}$ increases thereby resulting in a greater value for $_sE_R$. However, the results of the present

[7] This analysis applies to Experiment II.

[8] The second article of this series will report an experimental investigation which bears upon the problem of whether the obtained differences of our experimental groups could possibly be attributed to differences in relative amounts of habit strength ($_sH_R$), i.e. whether drive strength (D) is one of the variables determining the rate and amount of development of $_sH_R$.

[9] For simplicity's sake this formula is slightly different from the one appearing in the book (**6**).

[10] Warner (**14**) has discovered that male white rats would cross an electrically charged grill to obtain food more readily after four days of food deprivation than after 2, 3, 6, or 8 days. In terms of the methodology of the Warden obstruction box the maximum value of the hunger drive would occur after approximately four days of food deprivation.

experiments (I and II) are in conflict with such a formulation. In Experiment I a group of hungry animals learned a simple spatial discrimination more efficiently (less errors) than a group which was motivated by both hunger and thirst. The results of Experiment II revealed that the group with the strongest coexistent drive required less trials to extinguish a bar pressing response than did groups possessing an additional drive of weaker intensities.

It is necessary to formulate a new equation which will correct the deficiencies of equation 5. To be consistent with the results of Experiment II the additional drive must at first increase the drive strength (D) and after reaching a certain point begin to decrease it. One could formulate many equations which would behave in this required fashion. Unfortunately, too little is known about the growth of the hunger and thirst drives (independent of each other) from zero to 22 hours of deprivation. If these relationships were known, i.e., could be mathematically stated, then an equation might be derived which would express the interaction effects of thirst and hunger drives in a food reward situation.

Summary

The purpose of the present investigation was to observe certain interaction effects of hunger and thirst drives on learning in white rats. An initial experiment was conducted to study the effects of a relatively intense thirst drive upon the acquisition of a simple spatial discrimination habit with food serving as reward. The results revealed that the presence of the strong additional thirst drive retarded learning. In order to obtain a more complete picture as to the nature of the functional relationship holding between the rate of learning and the strength of the interacting drive, an experimental design involving the use of a Skinner box was formulated. Five groups of animals under different motivational conditions received 30 reinforcements of the bar depressing response. The hunger drive for all five groups was based on 22 hours of food deprivation, but the thirst drive was varied from group to group (0, 3, 6, 12, and 22 hours of water deprivation). Following the acquisition trials the five groups were extinguished under the same motivational conditions as their conditioning trials. The number of trials to reach the criterion of extinction was utilized as a measure of the strength of the bar depressing response.

In order to fulfill the assumptions of the analysis of variance, all extinction scores were transformed into $1000 \times \log_{10}$ values. The results of the analysis of the data indicated (1) that the varying degrees of thirst had a differential effect upon the response measures, and (2) that the response scores increased with increase of time of

water deprivation up to 12 hours but was greatly depressed at 22 hours of water deprivation.

The implications of the experimental results are discussed in terms of Hull's behavior theory.

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PROBLEM SOLUTION BY MONKEYS FOLLOWING BILATERAL REMOVAL OF THE PREFRONTAL AREAS. V. SPATIAL DELAYED REACTIONS

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I. Introduction

The use and importance of the delayed reaction test as a technique for investigation of the effect of large lesions of the prefrontal areas on subhuman primates was first emphasized by the work of Jacobsen and his co-workers (**21**, **22**, **25**). These investigators found that monkeys and chimpanzees failed to solve spatial delayed reactions tested by a direct method after bilateral removal of the prefrontal areas. They interpreted this deficit as a result of a loss of the capacity for 'immediate memory.' This type of behavioral adaptation appeared to be specifically dependent upon the prefrontal areas, since extensive bilateral lesions to the parietal, temporal, or motor and premotor areas occasioned no loss.

Jacobsen and Nissen (**24**) subsequently reported that the delayed alternation habit was also abolished by bilateral ablation of the frontal association areas. These results were 'in harmony with the effects of frontal injury on performance of delayed response.'

Finan (**2**) demonstrated that bilateral prefrontal monkeys could solve temporal discrimination problems, a shuttle box and a temporal discrimination maze. Attempting to relate these data to those of Jacobsen, he assumed that "temporal organization . . . can not be considered the mechanism of immediate memory."

In a second experiment (**3**), Finan found, as had Jacobsen, a complete loss of delayed response in two monkeys following bilateral ablation of the frontal association areas. Upon introducing pre-delay reinforcement, in which before each trial the animal received a reward in the food cup subsequently correct, the same two *S*s attained a level of correct response on 15-sec. delays significantly better than chance. These results led Finan to the assumption that the primary contribution of the prefrontal areas was that of a 'derived overt reinforcing agency' and not the retention of immediate experiences.

The problem of the role of the prefrontal areas was further complicated by the finding of Malmo (**29**) that monkeys could solve

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spatial delayed reactions run by an indirect technique offering maximal opportunity for the formation of positive after-images. Successful response was inversely related to the degree of illumination of the cage during the delay interval. The hypothesis was advanced that bilateral frontal lobectomy renders the animal more susceptible to 'retroactive inhibition.'

II. Purpose

The purpose of the present investigation was to study the effect of the bilateral ablation of the prefrontal areas on the performance of rhesus monkeys on spatial delayed reactions using a direct method of testing. To appraise the effect of emotional disturbances, graded, stepwise procedures were used throughout. In order to determine the time interval necessary for recovery, the postoperative period before the initiation of the present tests ranged in the various *Ss* from slightly less than three months to over three years.

III. Subjects

Six operated and six normal rhesus monkeys were used as *Ss* in the present experiment. The previous test history of these animals is indicated in Table I, in which the numbers in the parentheses refer to the references given at the end of the paper.

TABLE Ia

Preoperative and Postoperative Test Experience of the Operated *Ss*

Animal number	Test experience	
	Preoperative	Postoperative
54		(12), (13), (15), (16), (17), (19), (34)
55		(12), (13), (15), (16), (17), (19), (34)
64	(7), (8), (14), (33)	(14)
65	(7), (8), (14), (33)	(14)
22	(6), (8), (35), (38), (39)	(14)
57	(6), (8), (9), (35)	(14)

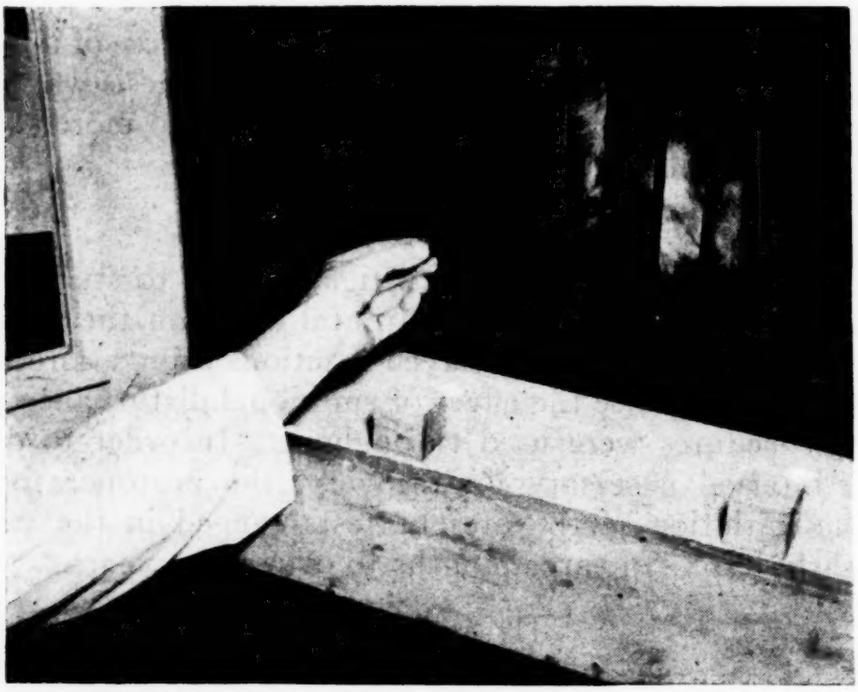
TABLE Ib

Test Experience of the Normal *Ss*

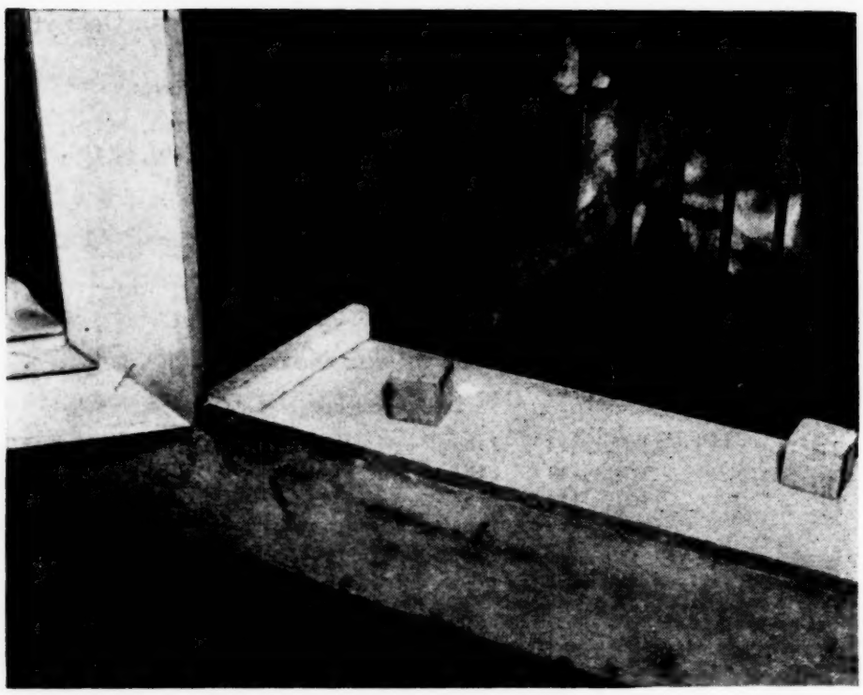
Animal number	Test experience
73	(10), (11), (18)
74	(10), (11), (18)
75	(10), (11), (18)
76	(10), (11), (18)
21	(6), (8), (18), (35), (38), (39)
56	(6), (8), (9), (18), (35), (38), (39)

IV. Apparatus

The general test situation used in this investigation, save for the fact that a mirror was placed at the side to make possible continuous observation of the animal, is the same as that described by Spaet and Harlow (**34**). The stimulus tray was the discrimination tray commonly used in earlier investigations and had two food wells set 12 in. apart, center to center. The objects used to cover the food wells during the delay intervals were two unpainted 1½ in. wooden cubes. The essential characteristics of the test situation, the stimulus tray and the stimulus objects are illustrated in Fig. 1.



1a. Food is shown to monkey preparatory to baiting correct food well.



1b. Monkey displaces correct object after delay interval and obtains reward.

FIG. 1. Solution of spatial delayed response by rhesus monkey 54

V. Method

Operative procedures

All operations were carried out in a single stage using full aseptic precautions.[1] The extent of the lesions is indicated in Table II, the numbers of the prefrontal areas being those described by Walker (36).

TABLE II

Operative Data Concerning the *Ss* *

Animal number	Extent of lesion			Gms. tissue excised		Mo. post-operative recovery
	Total	Severe	Partial	L	R	
54	8b, 9, 10, 11, 46	12, 25	8a, 13, 45	2.9	2.7	39
55	8b, 9, 10, 11, 46	12, 25	8a, 13, 45	2.8	3.0	39
64	8b, 9, 10, 11, 46	12, 25	8a, 13, 45	3.0	3.1	6
65	8b, 9, 10, 11, 12, 46	13, 25, 45	8a, 14, 24	3.5	3.5	4.5
22	8b, 9, 10, 11, 12, 46	13, 25, 45	8a, 14, 24	3.2	3.5	3
57	8b, 9, 10, 11, 12, 13, 46	14, 25, 45	8a, 24	4.1	3.8	4

* Drawings showing the exact amount of tissue excised in every animal are on record and will be sent upon request.

General test procedures

The delayed reaction problem was divided into three parts: (1) the preliminary training, (2) a delayed response series, in which increasingly long delay periods were introduced using stepwise procedures, and (3) a zero-sec. interspersed delayed response series, similar to the delayed response series but with zero-sec. delays interspersed among the longer delayed responses.[2]

A non-correction method (20) was used throughout and an inter-response food reward (31) was administered throughout except in case of failure on the zero-sec. trials.

For animals 54, 57, 64 and 65 and for all normal animals the baiting of the correct stimulus position was accomplished by showing a piece of food to the animal, dropping the food in the correct food well and simultaneously placing the stimulus-objects over the two food wells.

In the case of subjects 55 and 22, a stimulus-object was placed over the incorrect food well and the food reward shown to the monkey at the same time. The food was then dropped into the other food well both hands were withdrawn and both hands brought forward while placing the remaining stimulus-objects.

During the trials in which no screen was utilized the *E* held his hands over the stimulus-objects during the delay interval.

Preliminary training trials

Ten zero-sec. delayed reaction trials were run to the criterion of 9 correct out of 10 trials for two successive days, with the added provision that not less than five days of such training were to be given (Step PT-1).

[1] The operations on animals 54, 55 and 64 were carried out by H. F. Harlow and the operations on animals 65, 22 and 57 were carried out by Paul H. Settlage.

[2] This procedure was planned on the basis of personal communication with Dr. P. H. Settlage, who found that normal rhesus monkeys trained to solve spatial delayed reactions of long (45–60 sec.) duration often showed severe loss on, or complete disruption of, delayed response of any duration after repeated failure. The procedure employed was designed to reduce the effects of emotional disturbances arising from repeated failure at any point of the series upon the monkey's actual ability to solve problems involving delay.

Solution of this test was followed by 10 trials a day of alternate zero- and 5-sec. delayed reactions, again to the criterion of 9 correct responses a day for two successive days (Step PT-2).

An additional behavioral criterion was enforced in that the monkey was allowed circling behavior during the delay interval on not more than two trials of any day's run.[3] Whenever circling appeared the animal was not permitted to make a choice; instead, the trial was rerun.

The delayed response series

Twenty trials a day were run throughout the delayed response series. The criterion for solution of any step was 17 correct responses out of 20 trials for each of two successive days, a level of response significantly better than chance at the one percent confidence level. The animal was allowed four days to attain this level of success. The additional behavioral criterion used in the preliminary training trials also was enforced. Circling responses appeared only during the early part of this response series.

The following Tests and Steps and their essential characteristics are given below:

Test I:	(DR-I)	Neither the opaque screen nor the one-way-vision screen were utilized.
Step I	(DR-Ia)	zero-sec. delays alternating with 5-sec. delays
Step II	(DR-Ib)	5-sec. delays
Step III	(DR-Ic)	5-sec. delays alternating with 10-sec. delays
Test II:	(DR-II)	The opaque screen was interposed between the animal and the test situation on all save the zero-sec. delay trials.
Step I	(DR-IIa)	zero-sec. delays alternating with 5-sec. delays
Step II	(DR-IIb)	5-sec. delays
Step III	(DR-IIc)	5-sec. delays alternating with 10-sec. delays
Test III:	(DR-III)	The opaque screen was interposed between the animal and the test situation on all save the zero-sec. delay trials. The one-way-vision screen was interposed between the test situation and the *E* on all save the zero-sec. delay trials.
Step I	(DR-IIIa)	zero-sec. delays alternated with 5-sec. delays
Step II	(DR-IIIb)	5-sec. delays
Step III	(DR-IIIc)	5-sec. delays alternated with 10-sec. delays
Step IV	(DR-IIId)	10-sec. delays
Step V	(DR-VIIe)	10-sec. delays alternated with 15-sec. delays
Step VI	(DR-IIIf)	15-sec. delays
Step VII	(DR-IIIg)	15-sec. delays alternated with 20-sec. delays
Step VIII	(DR-IIIh)	20-sec. delays
Step IX	(DR-IIIi)	20-sec. delays alternated with 30-sec. delays
Step X	(DR-IIIj)	30-sec. delays
Step XI	(DR-IIIk)	30-sec. delays alternated with 45-sec. delays
Step XII	(DR-IIIl)	45-sec. delays
Step XIII	(DR-IIIm)	45-sec. delays alternated with 60-sec. delays
Step XIV	(DR-IIIn)	60-sec. delays

Regression following failure was always instituted and was thought to be an essential part of the test. In the case of failure on any step of any test, the animal regressed one step within the same test (a partial regression). If the monkey passed this step, he again advanced to the step above; if the animal again failed he regressed to that step of Test I (DR-I) corresponding in length of delay interval to the step just failed or to DR-Ic if Test I offered no corresponding delay interval. In the case of further failure the *S* regressed through all the steps of DR-I. This was called a complete regression. If DR-Ia was failed, the animal was given preliminary training (zero-sec. delay), differing from the original preliminary training in that 20 trials a day were run. This step was labeled PT-3. If at any point during the regression steps the animal met the criteria, he progressed forward in the stepwise order already outlined.

As soon as any monkey solved test DR-IIIn he was tested on a second series—the ZS series. All *S*s who failed to solve any DR-III step were run on the ZS series after they had made two

[3] Circling is not to be confused with pacing or mere hyperactivity. Pacing back and forth or from side to side did not constitute circling behavior.

Complete Regressions (regressed from any step of Test DR-II or DR-III to DR-Ia or PT-3) or five Partial Regressions.

The Zero-Sec. Interspersion Series (ZS-series)

In the ZS series 30 trials a day were presented, 20 of which were always zero-sec. delays and 10 of which increased in length with each step in the series as follows: 5 sec., 10 sec., 15 sec., 20 sec., 30 sec., 45 sec., and 60 sec.

The interspersion of the zero-sec. delay trials followed a predetermined irregular order. Using two basic zero-sec. presentation series 2-3-3-2 and 1-4-4-1, four presentation series were possible (2-3-3-2-2-3-3-2; 1-4-4-1-1-4-4-1; 2-3-3-2-1-4-4-1; and 1-4-4-1-2-3-3-2). The 10 longer trials were then placed after each zero-sec. trial group in such a manner that the daily series always began with a zero-sec. trial rather than with a long delay. Since there were eight zero-sec. trial groups, there were also eight positions in which the 10 longer delay trials could be placed; consequently, at least two of these longer delay positions contained two longer delay trials. Of the many possible combinations, the following 15 were utilized, and in the following order:

a) 2* 3 ** 3 * 2 * 2 * 3 * 3 ** 2 *
b) 1 * 4 ** 4 ** 4 ** 1 * 1 * 4 ** 4 * 1
c) 2 * 3 * 3 * 2 * 1 * 4 ** 4 ** 1 *
d) 1 * 4 ** 4 ** 1 * 2 * 3 * 3 * 2 *
e) 2 * 3 ** 3 ** 2 * 2 * 3 * 3 ** 2
f) 1 * 4 ** 4 * 1 * 1 * 4 ** 4 ** 1
g) 2 * 3 * 3 ** 2 * 1 * 4 ** 4 * 1 *
h) 1 * 4 ** 4 ** 1 * 2 * 3 * 3 ** 2
i) 1 * 4 * 4 ** 1 * 1 * 4 ** 4 * 1 *
j) 2 * 3 ** 3 * 2 * 1 * 4 ** 4 ** 1
k) 1 * 4 ** 4 * 1 * 2 * 3 * 3 ** 2 *
l) 2 * 3 ** 3 * 2 * 2 * 3 ** 3 ** 2
m) 1 * 4 * 4 * 1 * 1 * 4 ** 4 ** 1 *
n) 2 * 3 ** 3 ** 2 * 1 * 4 ** 4 * 1
o) 1 * 4 * 4 ** 1 * 2 * 3 ** 3 ** 2

(Note.—Numbers here refer to the number of zero-sec. trials presented; each asterisk represents one longer delay trial.)

The criterion for the solution of any step of the ZS-series was 17 correct responses out of any consecutive 20 of the longer delay trials (a two-days' run).

Following is the stepwise procedure for the ZS-series:

Test I:	(ZS-I)	Neither the opaque screen nor the one-way-vision screen was utilized.
Step I	(ZS-Ia)	zero-sec. delays and 5-sec. delays
Step II	(ZS-Ib)	zero-sec. delays and 10-sec. delays
Test II:	(ZS-II)	The opaque screen was interposed between the animal and the test situation on all save the zero-sec. delay trials.
Step I	(ZS-IIa)	zero-sec. delays and 5-sec. delays
Step II	(ZS-IIb)	zero-sec. delays and 10-sec. delays
Test III:	(ZS-III)	The opaque screen was interposed between the animal and the test situation on all save the zero-sec. delay trials. The one-way-vision screen was interposed between the test situation and the *E* on all save the zero-sec. delay trials.
Step I	(ZS-IIIa)	zero-sec. delays and 5-sec. delays
Step II	(ZS-IIIb)	zero-sec. delays and 10-sec. delays
Step III	(ZS-IIIc)	zero-sec. delays and 15-sec. delays
Step IV	(ZS-IId)	zero-sec. delays and 20-sec. delays
Step V	(ZS-IIIe)	zero-sec. delays and 30-sec. delays
Step VI	(ZS-IIIf)	zero-sec. delays and 45-sec. delays
Step VII	(ZS-IIIg)	zero-sec. delays and 60-sec. delays

As with the DR-series, regression was always instituted after failure in any step, and the same procedure of regression was used. If Step ZS-Ia was failed, regression was to a step consisting of 30 trials of zero-sec. delays.

VI. Results

A. Adaptation to the delayed reaction test situation

In Table III and in Fig. 2 are presented data indicating the degree of success attained by the normal and the operated *Ss* in

TABLE III

Highest Percentage of Correct Responses Made in Any One Day on the Maximum Delay Interval of Step PT-1 and Each of the Steps of Series DR-I

Operated animals					Normal animals				
Number	Steps				Number	Steps			
	PT-I*	DR-Ia†	DR-Ib‡	DR-Ic§		PT-I*	DR-Ia†	DR-Ib‡	DR-Ic§
54	100	100	100	100	73	100	100	100	95
55	100	100	100	95	74	100	90	100	100
64	100	100	75	50	75	100	95	100	100
65	100	90	95	60	76	100	100	100	95
22	100	80	55	50	56	100	100	100	100
57	90	60	50	50	21	100	100	95	85
M	98	88	79	68	M	100	97.5	99	96

Maximum delay interval of the various steps
* = zero sec.
† = 5 sec.
‡ = 5 sec.
§ = 10 sec.
In those cases in which a monkey failed to reach a particular step an arbitrary score of 50 percent was given.

adapting to the delayed reaction test situation. These are data taken from Step PT-1 and the Dr-I series, maximum delay intervals being 10 sec. Since no interfering screens were used in these tests, an extremely simple and direct test situation is presented to the animal. The data show each monkey's best day's score for the maximum delay interval for Step PT-1 and each of the steps of the DR-I series.

All of the normal *Ss* adapted rapidly and successfully to the delayed reaction situation. There is little difference between the scores of the worst and the best *S*, and these differences are not indicative of later performance. Only two of the operated animals, 54 and 55, successfully adapted to the delayed reaction tests. The differences between the scores of these *Ss* and the worst *Ss*, 22 and 57, is a difference between complete success and almost complete failure. These data show that monkeys with extensive lesions of the prefrontal association areas frequently fail to adapt to the delayed reaction

test situation. This failure is not to be confused with a mere reduction of any mythical maximal delay interval.

B. Maximum length of delay attained

A comparison of the maximal length of delay achieved by the normal and the operated animals is given in Fig. 3. The total number of trials taken and the percentage of correct responses made on each step of all tests is presented in Table IV. The data indicate

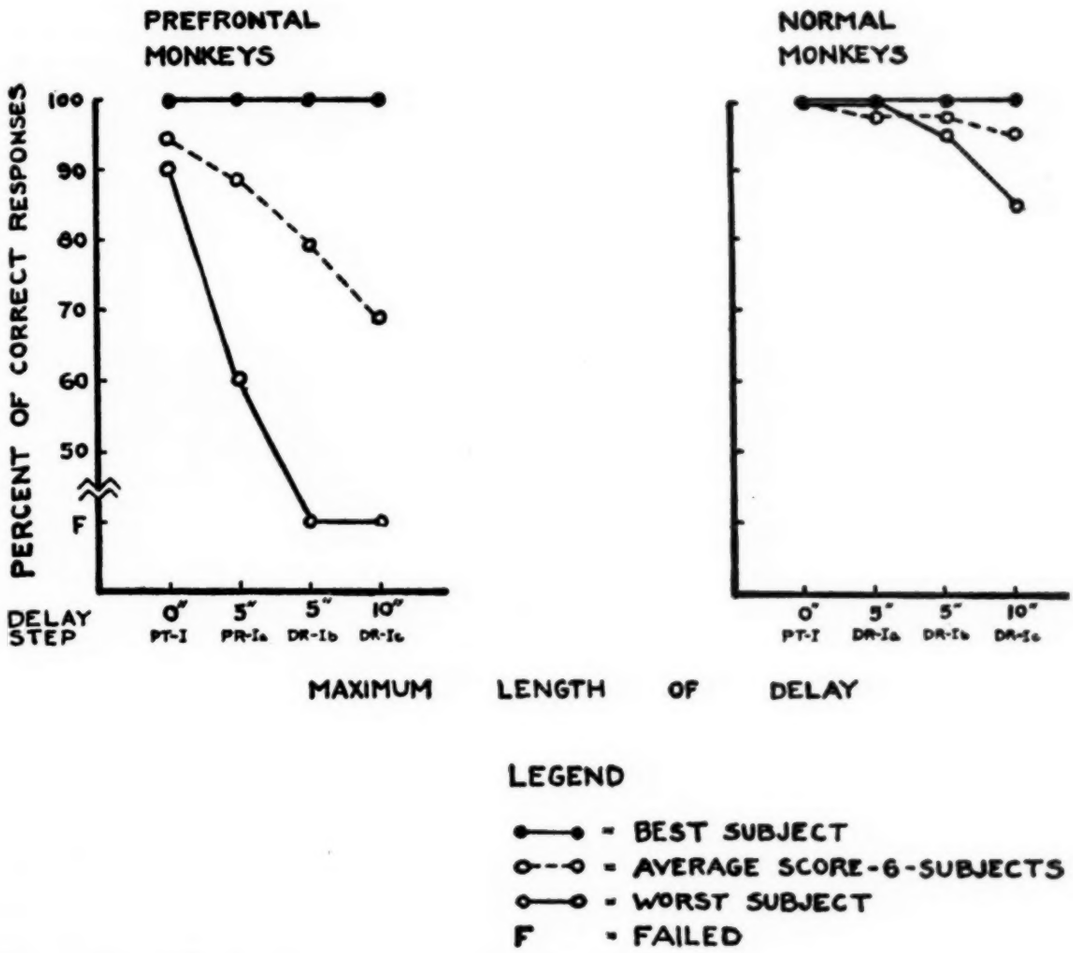


FIG. 2. Highest percentage of correct responses made in any one day on the maximum delay interval of step PT-I and each of the steps of series DR-I

the difficulty that the normal Ss met in the solution of delayed reactions even of moderate length, particularly when the opaque and the one-way vision screens were used. No attempt was made to test any 'limit of ability' of the rhesus monkey in delayed reaction performance. These data indicate, however, that normal rhesus monkeys do not easily solve delayed reactions of moderate length when tested under rigid and predetermined test conditions, in test situations of the type described.

Two of the prefrontal *Ss*, 54 and 55, made scores comparable to those of the best of the normal *Ss*. Only one other operated animal, 65, gave any evidence of mastering the delayed reaction problem. This *S* solved 10-sec. delayed reactions (Step ZS-IB), but failed either to go beyond this point or even maintain this score in later tests. Subjects 22 and 57 encountered difficulty in delayed reactions of any appreciable length.[4]

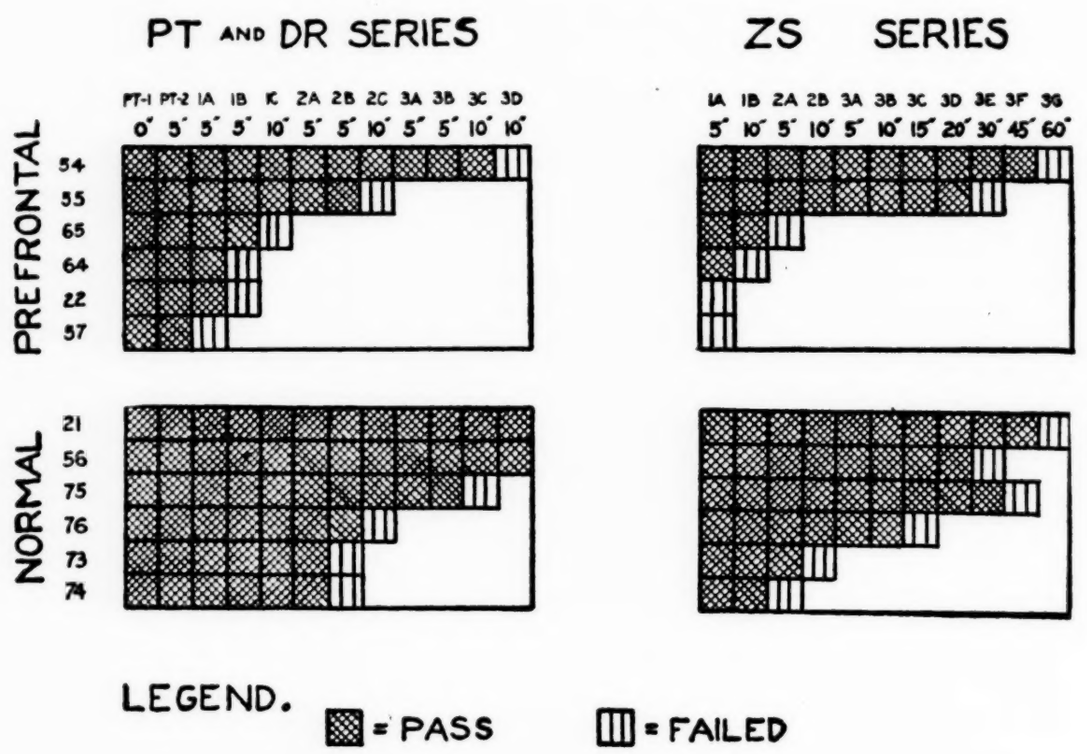


FIG. 3. Maximum length of delay by normal and prefrontal monkeys

All normal *Ss* solved 10-sec. delayed reactions (Step DR-IC and Step ZS-IB). The two monkeys whose scores were the poorest (73, 74) were given tests on an extended ZS-I Test at the conclusion of the regular experiment. Both *Ss* solved 30-sec. delayed reactions in these supplementary tests.

C. Influence of lesion size

The two *Ss* of the prefrontal group to achieve the longest delays, 54 and 55, were the animals with the smallest lesions as indicated by weight of the excised tissues and observation of the excised tissues. Subjects 22 and 57, with very large lesions (including extensive

[4] Subjects 64, 65, 22 and 57 had solved 15-sec. delayed reactions in brief preliminary pre-operative tests.

TABLE IV

TOTAL NUMBER OF DELAYED REACTION TRIALS AND THE PERCENTAGE OF CORRECT RESPONSES

TABLE IVa

Total Number of Trials

	Subj. No.	PT-1 0″	PT-2 5″	1A1B 5″	1C 10″	2A2B 5″	2C 10″	3A3B 5″	3C3D 10″	1A 5″	1B 10″	2A 5″	2B 10″	3A 5″	3B 10″	3C 15″	3D 20″	3E 30″	3F 45″	3G 60″
Operated	54	100	35	218	58	180	40	66	86	30	20	20	20	20	20	20	20	20	20	18
	55	155	40	319	40	287	30			40	80	70	40	100	80	160	30	50		
	65	100	35	260	20					50	20	20								
	64	100	40	150						435	40									
	22	70	10	110						60										
	57	245	75	30						50										
Normal	21	60	10	190	10	120	30	80	60	20	20	20	20	60	40	40	40	70	60	40
	56	75	15	175	10	80	20	80	60	20	20	20	10	20	20	50	80	20		
	75	20	20	160	60	370	60	100	20	20	20	60	80	40	40	40	30	20	20	
	76	30	20	95	20	430	30			60	100	30	20	70	70					
	73	80	20	300	20	90				40	90	120	50							
	74	60	10	250	70	180				40	60	50								

TABLE IVb

Percentage of Correct Responses

	Subj. No.	PT-1 0″	PT-2 5″	1A1B 5″	1C 10″	2A2B 5″	2C 10″	3A3B 5″	3C3D 10″	1A 5″	1B 10″	2A 5″	2B 10″	3A 5″	3B 10″	3C 15″	3D 20″	3E 30″	3F 45″	3G 60″
Operated	54	65	69	98	98	87	85	86	84	87	95	95	100	95	95	90	100	85	90	56
	55	86	80	87	98	87	67			93	94	84	85	87	84	93	80	56		
	65	83	69	77	60					72	90	40								
	64	72	75	65						69	50									
	22	83	80	62						53										
	57	72	59	63						70										
Normal	21	100	100	88	70	89	80	100	100	95	100	100	90	87	93	90	90	73	70	58
	56	77	80	84	100	99	100	95	93	85	90	100	100	100	100	80	69	65		
	75	100	100	95	97	80	72	84	65	100	100	88	75	90	78	82	77	85	50	
	76	97	100	93	85	74	70			83	100	76	80	85	76	63				
	73	95	90	82	95	67				93	96	71	58							
	74	87	90	90	94	58				98	97	58								

Seconds (0″, 5″, etc.) = Maximum delay interval for each step.

The total number of trials and the percentage of correct responses are given only for the maximum delay interval.

damage to areas 13, 14 and 45), failed completely on the ZS series and did little better on the DR series. Subjects 64 and 65 made intermediate scores, but more closely approximated the worst than the best.

In discussing the effect of lesion size it should be emphasized that the lesions were large in the case of all six *S*s, and that in all animals the greater portion of the prefrontal association areas were removed. Furthermore, the description of the lesion size was based on observation of tissue cleanly excised, and the actual damage was doubtless somewhat greater than that described.

On the basis of these results it can be stated that the finding attributed to Jacobsen by Fulton (**4**, p. 426), that areas 9a and 10 are the areas whose destruction produced the deficit in delayed reactions, needs considerable qualification.

D. Influence of duration of postoperative recovery

The monkeys with the longest time interval between operations and testing, 54 and 55, achieved a level of success definitely superior to that of the other *S*s with bilateral prefrontal lobectomy. The time lapse here was over three years. All of the other *S*s were tested within six months of operation and the tests were completed within a year. Of these *S*s the one with the greatest time interval since operation, 64, was consistently inferior to subject 65; a six months as opposed to a four and a half months postoperative period was involved.

Other investigators (**3**, **22**, **29**) have commonly begun testing within two weeks to two months of operation and have completed their experiments within four to eight months of operation. Thus, we suspect that in many cases the brains of the monkeys were hardened in formaldehyde before they had fully recovered from the effects of the operation. Our observations indicate that recovery from the effects of ablation of the frontal association is slow, and these observations are supported by the data of operations on man.

Our own data are at present incomplete in that the monkeys with the smallest lesions are also those with the longest postoperative period of recovery.

E. Behavioral changes

General postoperative behavioral changes.—All the monkeys with bilateral destruction of the prefrontal association areas showed marked hyperactivity, consisting of circling, pacing, and over-response to extraneous stimulation (see **26**, **28**). This behavior was particularly exaggerated in subjects 22 and 57. If these animals

were even casually observed by an experimenter they would fly into violent and prolonged outbursts of random activity. For over a month it was thought that neither monkey could possibly ever be tested. Their behavior was similar to that described by Ruch and Schenkin (**32**) for monkeys following excision of areas 13 (an area without question very badly damaged in their cases) and was more uncontrolled than that of any other prefrontal monkey subjected to psychological tests. Both animals gradually recovered and adapted surprisingly well to the test cage. Subject 57, a year after operation, gave vent to these violent and uncontrolled outbursts of random activity when excited.

Subject 22 had left homonymous hemianopsia for about 10 days' duration after operation. Subject 57 gave evidence of a type of behavior described by Klüver (**27**) for a monkey following destruction of the prefrontal areas. The animal would accept food as rapidly as proffered, often dropping already obtained handfuls to accept more. Subject 65 developed an exaggerated to-be-groomed-and-petted response (see Kennard, Spencer and Fountain, **26**). As soon as she was touched and stroked her restless behavior ceased, and she would sit perfectly still with head drawn back and eyes closed for considerable periods of time. The stitches were removed from her head five days after operation while she sat quietly in a corner of her cage without being restrained in any manner whatsoever! This monkey responded positively and apparently pleasurably to the removal of the stitches. These exaggerated to-be-groomed responses persisted for about 10 days and then faded. Transient evidence of similar responsiveness appeared in subject 57 in the first week after operation before its wild flights of unrestrained behavior fully developed.

Behavioral changes in the test situation.—The restlessness, pacing, and circling noted as general behavioral changes following bilateral prefrontal lobectomy were also apparent in the test situation, where the pacing was often (especially 22 and 57) so compulsive and violent as to cause complete inattention by the animal to the stimulus-objects. The inattention of the prefrontal animals—a condition reported in human clinical studies (**1**, **5**, **30**)—was apparently a result not only of this pacing and circling activity, but of a generally lowered threshold of excitation to all external and internal stimuli as well.

The experimental group as a whole was further distinguished by a relatively quick loss of motivation in the test situation, with the possible exception of subject 22. Since this loss of motivation in all cases was preceded by periods of repeated failure, this was taken as a definite reaction to frustration and failure. None of the four subjects

(21, 22, 56, and 57) which had been given preliminary preoperative delayed reactions had refused to test on the preoperative test trials.[5]

All of the prefrontal animals showed refusals to work (a fact substantiated also on many other tests) in opposition to reports of complete indifference to failure now in the literature (**24, 37**). Finan (**3**) has mentioned resistance to work on the part of his monkeys. The refusal to work in itself differentiated the operated from normal animals, for the pattern of behavior was different from that commonly found in the normal monkey after repeated failure. The normal animal typically retreats to the rear of the testing cage and remains indifferent to the test situation or gives vent to aggressive behavior. Frustration on the part of the prefrontal animals (especially 57 and 65) was accompanied by violent outbursts of activity so intense as to preclude any possibility of testing. The monkey would circle rapidly about the cage, jump up and down, and pace back and forth; under such conditions the animal could not respond to the original exhibition of the stimulus objects. If the trial was run, nevertheless, the *S*s chose wildly (if he temporarily became quiet enough to choose at all), and often removed the food from the well only to drop it indifferently on the floor of the testing cage. It was noted that in such circumstances the monkey would frequently refuse to accept free food, a condition not found in the frustrated normal animal.

These refusals or failures to work appeared in the operated monkeys after some semblance of adaptation to the delayed reaction problem had been accomplished—not ordinarily on the zero-sec. delayed reactions.

Discussion

Comparison of related studies

The results of our experiment, combined with the work of other investigators, make it appear that the spatial delayed reaction tested by the direct method is drastically affected by bilateral removal of the prefrontal association areas. Such problems have never been solved by a monkey within a year of operation without special subsidiary training [see Jacobsen (**21, 22**), Finan (**3**), and the present results].

The data of the present experiment indicate that after prolonged periods of recovery and other postoperative test experience the rhesus monkey may solve spatial delayed reactions tested by the

[5] Two monkeys, 54 and 55, were trained to do spatial delayed reactions using a combined matching-non-matching from sample method. The technique was that described by Spaet and Harlow (**34**) save that on the non-matching trials there was no food under the sample object. In spite of the fact that there was no opportunity for the monkeys to benefit by any pre-delay reinforcement on the non-matching trials the prefrontal monkeys solved 10-sec. delayed reactions and made scores superior to two normal control animals, 51 and 53, selected as the best test animals in the laboratory.

direct method. Supporting evidence is to be found in the report by Finan (3, p. 208).

It appears likely that less severe loss is occasioned if the tests are carried out using some indirect method of testing the spatial delayed reaction [see Malmo (29), Spaet and Harlow (34), and this paper, footnote 5].

There are some data to indicate that the severity of the deficit may be related to the amount of tissue destroyed in the frontal lobes. Jacobsen (21) has indicated that partial destruction of the prefrontal areas occasions a deficit in delayed reaction performance less severe than that resulting from total destruction of these cortical regions. Our own data indicate that the severity and duration of deficit may be related to the amount of tissue destroyed. Whether these results arise from intellectual loss or from other and secondary behavioral disturbances has not been demonstrated.

The problem of the effects of frustration upon the monkey deprived the prefrontal association areas remains unsolved. Differences in the literature may result from differences in the problems tested and the procedures used in testing these problems, from pretest differences in the tameness of the animals and the degree to which they had been adapted to the test situation, from differences in the performance of the animals on the test problems after operation, and from differences in the post-operative recovery period. Our own data indicate that thoroughly tamed rhesus monkeys following recovery from bilateral prefrontal lobectomy give as much or more evidence of frustration—as indicated by refusal to continue work on a problem—as do normal intact monkeys. Jacobsen and Nissen (24) and Warden, Barrera and Galt (37) have independently described marked reduction in the severity of frustration responses following bilateral prefrontal lobectomy.

Nature of the intellectual deficit

There is considerable evidence to suggest that failure on the part of monkeys with large lesions in the prefrontal areas to adapt readily to the delayed reaction situation is in large part a failure to attend effectively to the presentation of food under the stimulus correct on any one trial. Thus, the *S*s fail to fixate and differentiate the cues essential for problem solution. As a result of this inability to attend and fixate effectively the monkey either fails to learn or fails to establish an association strong enough to override the interfering effects of the responses made to earlier trials or to the effects of extraneous stimuli. Any factor which facilitates attention and fixation of the position of the correct stimulus will facilitate delayed reaction solution.

A pre-delay reinforcing trial obviously accomplishes this, and Finan (**3**) has found that it materially aids in the solution of delayed responses by frontally ablated monkeys. However, pre-delay reinforcement is not necessary for such solution. Delayed reactions run by indirect methods are also solved by monkeys following extensive frontal lesions. One may reasonably assume that the earlier prolonged pre-delay discrimination training heightens the attentive value of the stimulus. The results of Malmo (**29**) and Spaet and Harlow (**34**) are in keeping with this assumption. Unpublished data by Harlow (this paper, footnote 5) also support this theory. Anyone who has trained normal rhesus monkeys to solve delayed reactions using a direct method will recognize the difficulty of getting the monkeys to learn to attend to the presented food, and this difficulty is greatly exaggerated following bilateral removal of the prefrontal areas, particularly after the *S* has made errors in any day's testing. The observation that the excited prefrontal rhesus monkey may not even attend to proffered food suggests that the attentive function suffers widespread impairment. Similar loss appeared in the tests of initiation of behavior reported by Harlow and Johnson (**17**).

It must be admitted that 'loss of attention' cannot be defined in any fully satisfactory manner. The monkeys have difficulty in orienting toward, and maintaining this orientation to, a limited portion of the test situation. 'Attention' is not lost but is impaired. The animal is easily distracted at the time that the correct cup is being baited. A monkey may respond in a satisfactory manner for several trials and then completely fail to attend, particularly after error. The macaque does better if any indirect method is used than it a direct method is used. But even with the former, the attentive responses of the *S* are far from stable, *particularly in the recovery period lasting for at least several months.*

In essence, it is our belief that the difficulty that monkeys have in solving spatial delayed reactions results more from failure to establish firmly an association between the position of the correct stimulus and the implicit food reward, and to differentiate these cues from the rest of the test situation, than it is a fading of any mnemonic trace or loss of memory. Our position is similar to that of Finan (**3**) and is in no essential position at variance with any detailed analysis made by Jacobsen.

Bilateral destruction of the prefrontal areas in monkeys produces deficits resulting in impaired performance on many different kinds of tests. Whether this deficit is the result of loss on a single intellectual function or many has not been clearly demonstrated and is beyond the province of this paper.

VII. Summary and Conclusions

1. Twelve rhesus monkeys, six normal animals and six which had been subjected to bilateral prefrontal lobectomy, were tested on spatial delayed reactions, using a direct method.

2. Two of the operated monkeys solved 20-sec. (or longer) delayed reactions, performances comparable to the best of the normal animals. The other four operated monkeys adapted poorly to the delayed reaction tests.

3. The performance of monkeys following extensive bilateral lesions of the prefrontal association areas appears to be influenced by the length of the postoperative recovery period, previous test history, and extent of the lesion within the prefrontal areas.

4. It is suggested that monkeys, following destruction of the prefrontal association areas, suffer deficit in attending and fixating limited aspects of a test situation, and that this operates to reduce the effectiveness of the acquisition of complex problems such as the delayed reaction run by the direct method.

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STATIC EQUILIBRIUM AND VESTIBULAR FUNCTION *

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Man's ability to maintain erect and stable posture results from the integration of stimuli from several sensory receptors, among them, presumably, the vestibular apparatus (**6**). The extent to which man depends on vestibular functions to maintain normal posture has not been clearly demonstrated, although Edwards contends that a cause of large body sway is 'defective vestibular activity' (**5**, p. 188).

The sense organs of the vestibular labyrinth consist of the ampullae of the semicircular canals, one on each canal, and the utricular maculae located at the common end of the three canals of each ear. A third portion, the sacculus, has been reported to be unimportant in functions of equilibrium (**10**, p. 87; **12**). Loss of function of the ampullae of the semicircular canals and the utricular maculae might logically be expected to influence or modify posture by two general types of activity; (1) reduction of afferent impulses to the muscles, resulting in generally decreased tonus, and (2) elimination of cues arising in the labyrinth as a result of body movement or displacement. It has been shown in lower animals that posture can be maintained despite loss of utricular functions but that loss of ennervation from the semicircular canals results in serious disturbances in posture (**11**). Such findings tend to focus attention on the ampullae of the semicircular canals as a source of control of equilibrial movements. Lowenstein and Sand have demonstrated that this organ has a neural discharge in both a resting and accelerating state (**9**). Accepting this as evidence that the ampullae may act as static regulators of posture, literature covering the effects of the loss of this function in man and other animals is pertinent.

Dusser de Barenne in discussing labyrinthine function stated: "The fact that the effects of labyrinthectomy are less pronounced in the higher animals and least so in man is important. It indicates that the influence of the labyrinth on the motor mechanisms becomes less and less as one ascends the vertebrate scale" (**3**, p. 225). Rademaker observed that individuals having bilateral destruction of VIII nerve functions usually have no difficulty in standing in the Romberg

* The material in this article should be construed only as the personal opinion of the writer and not as representing the opinion of the U. S. Navy Department.

position, and that they are able to adjust to slow inclinations induced by tilting platforms (**15**). De No demonstrated that loss of muscle 'tone' was regained in a few days following labyrinthectomy in experimental animals (**1**). Spiegel after a review of the literature stated that "the hypotonia regresses rather rapidly after the operation, in cats and dogs in a few hours or days, in rabbits and monkeys after several weeks" (**16**, p. 1651). It is apparent that although the ampullae of the semicircular canals may exert a static regulatory effect on posture, loss of function of this organ is not accompanied by such changes that body sway could, as Edwards claims, be used to 'facilitate the diagnoses of the extent of vestibular injury' (**5**, p. 187). This would be especially true of Edward's subjects since they were cases of loss of vestibular function of long standing.

The other consideration, the so called dynamic action of the ampullae, or response to motion, has now to be discussed. Thresholds to movement have usually been studied by using eye or head movements as the criterion of stimulation (**2**, **14**). An exception to this is the work of Lowenstein and Sand, who recorded action potentials directly from a nerve fiber from the ampulla of a ray (**9**). They reported a threshold value of 3°/sec.[2] Accelerations as large as these may be noted in body sway but usually occur only at the end of muscular compensation for body movement. Hence, the ampullae would not be expected to be the sense organ initiating the compensation since its threshold would be reached only upon active compensation.

Dodge determined thresholds to rotation in man, using eye movement as the criterion (**2**). His results are not given in terms of acceleration but as the extent of movement at 'sudden onset' and were expressed as angular velocity. He found that consistent responses were observed only with movement having a terminal velocity of 4°/sec. or more. Accepting for the time being the lowest value 2°/sec. for purposes of this discussion, then a five-foot ten-inch man would have to sway the equivalent of 2.4 inches per second, starting from rest, to stimulate the labyrinth ($r = r\omega$, or $70''.2\pi/180 = 2.4$ inches). This would assume the height of the *S* as the radius of a circle, his feet or ankles being the center of rotation. While it is possible to observe movements equivalent to 2.4 inches per second in some *S*s, they are infrequent, and even casual observation will reveal that most movements associated with body sway would be sub-threshold as considered in terms of angular velocity.

In contrast to the value reported above for thresholds of the labyrinth to movement, Miles (**13**) quoted Goldscheider's work as indicating that the thresholds for sensitivity to movement in large joints were 0.75 to 1.50 degrees. It appears that receptors in joints

probably play a more important role in movements associated with body sway than do end organs in the labyrinth.

This brief review of the literature serves to support the view that the receptors in the labyrinth are insensitive to fine body movements, and that functional loss of these receptors would not impair the perception of or response to movements associated with body sway. This is in keeping with Rademaker's findings that human *Ss* with such loss were able to compensate for small displacements but lost their balance with larger movements for which a normal subject could compensate and maintain balance (**15**). It is the problem of this paper to demonstrate this thesis with relevant clinical and experimental data.

Procedure

Two experimental procedures were employed to investigate the possible relation between vestibular function and body sway, (1) the measurement of body sway and other observations on a male *S* manifesting complete loss of function of the vestibular apparatus, and (2) observation of vestibular function, Barany Chair tests, and body sway in 45 *Ss* with intact labyrinths.

The measurement of body sway of the *Ss* reported in this study consisted of kymographic records of anterior-posterior sway, feet in V position (**6**, **13**). Two trials with eyes open and two trials with eyes closed were made in each case. Each trial was two min. in length with a 30-sec. rest period between trials. The graphic records were scored by measuring the length of the line with a Dietzgen map measure, and subtracting the horizontal movement due to the kymograph rotation. Scores are reported as millimeters of movement in two min.

The rail-walking test used with the patient manifesting loss of vestibular functions was similar to that described by Heath (**8**).

Conventional Barany Chair tests were run on the *Ss* in both right and left directions, with the head in the 30 degree forward position. A motor-driven 30 R.P.M. Barany chair was used with 10 rotations per test. Nystagmus was timed by an observer using a stop watch. The values used in this study represent the mean nystagmus time of the right and left rotations. Duration of the nystagmus in the two directions was correlated to the extent of an r of 0.79 ($N = 52$).

Results

The *S* demonstrating complete loss of vestibular functions was a 19 year old male convalescing from acute meningococcus meningitis whose last symptoms occurred within three months of the observations reported in this paper. The loss of vestibular function was determined by complete absence of response to the caloric test and to rotation in the Barany Chair; both tests were repeated on several occasions. The *S* was also suffering from complete bilateral deafness as a result of the infection.

Measurements of body sway were made on this *S* one month apart. At the first session the *S* had a mean sway of 488 mm. with eyes open, and a mean sway of 1901 mm. with eyes closed. No unusual qualitative features appeared in the *S*'s records with eyes open. With eyes closed, several large movements occurred not usually noted in normal *Ss*. The *S* appeared to lean gradually

forward upsetting his equilibrium to the point where he would suddenly have to stand erect to maintain his balance, in a reaction very akin to a startle response. He did not lose his balance to the extent that he had to shift his feet to prevent falling. The records of these trials were unlike those of normal *Ss* in that the large total sway was the result of a few large movements instead of to the usual fine oscillatory type of sway.

One month later, just prior to the *S*'s discharge from the hospital, body-sway measurements were again taken. The mean sway at this time with eyes open was 531 mm. and 1043 mm. with eyes closed. This represents an improvement from the previous session with the eyes closed and was particularly notable in that the *S* no longer swayed to the point of losing balance momentarily, as he did in the first session. Qualitative observation of the *S*'s performance supported the conclusion that he made a very real improvement in his ability to maintain stable posture during the month interval. The records for the last session are presented in Fig. 1 and can be compared with an *S* of average sway and with an *S* having considerable body sway but no detectable vestibular defect. No physical defects appeared in the latter *S* to account for his considerable movement. Other than being quite susceptible to seasickness the *S* appeared normal in all other observable respects including vestibular functions.

It was impossible for the meningitis patient in either test session to perform the rail-walking test to any scorable degree. In both sessions the *S* could not place his second foot on the rail in a balanced position to proceed to walk. During the second observation period the *S* was tried on one-inch, two-inch, and four-inch rails without his achieving any success. Whether this loss of dynamic equilibrium was incurred as a result of vestibular involvement, or occurred as a result of other lesions, is impossible to determine at this point. Similar observations on other patients might elucidate the general nature of the phenomenon.

In treating the data of the 45 normal *Ss* correlation coefficients were determined for the relations between body-sway measurements and post rotational nystagmus. Three correlation coefficients calculated are shown in the following table:

	Correlation with nystagmus (r) $N = 45$
Body sway, eyes open	$r = -.02$
Body sway, eyes closed	$r = .03$
Body sway, eyes open/eyes closed	$r = .08$

Since the standard error of a zero r for 45 cases is 0.15, it is readily apparent that there is no correlation between the body-sway measurements and nystagmus time significantly greater than zero.

One might expect a low correlation between body sway with eyes open and nystagmus, since body sway with eyes open is to a great extent dependent on vision. However, the zero correlation between body sway with eyes closed and nystagmus is indication that vestibular function, as measured by nystagmus, is unrelated to body

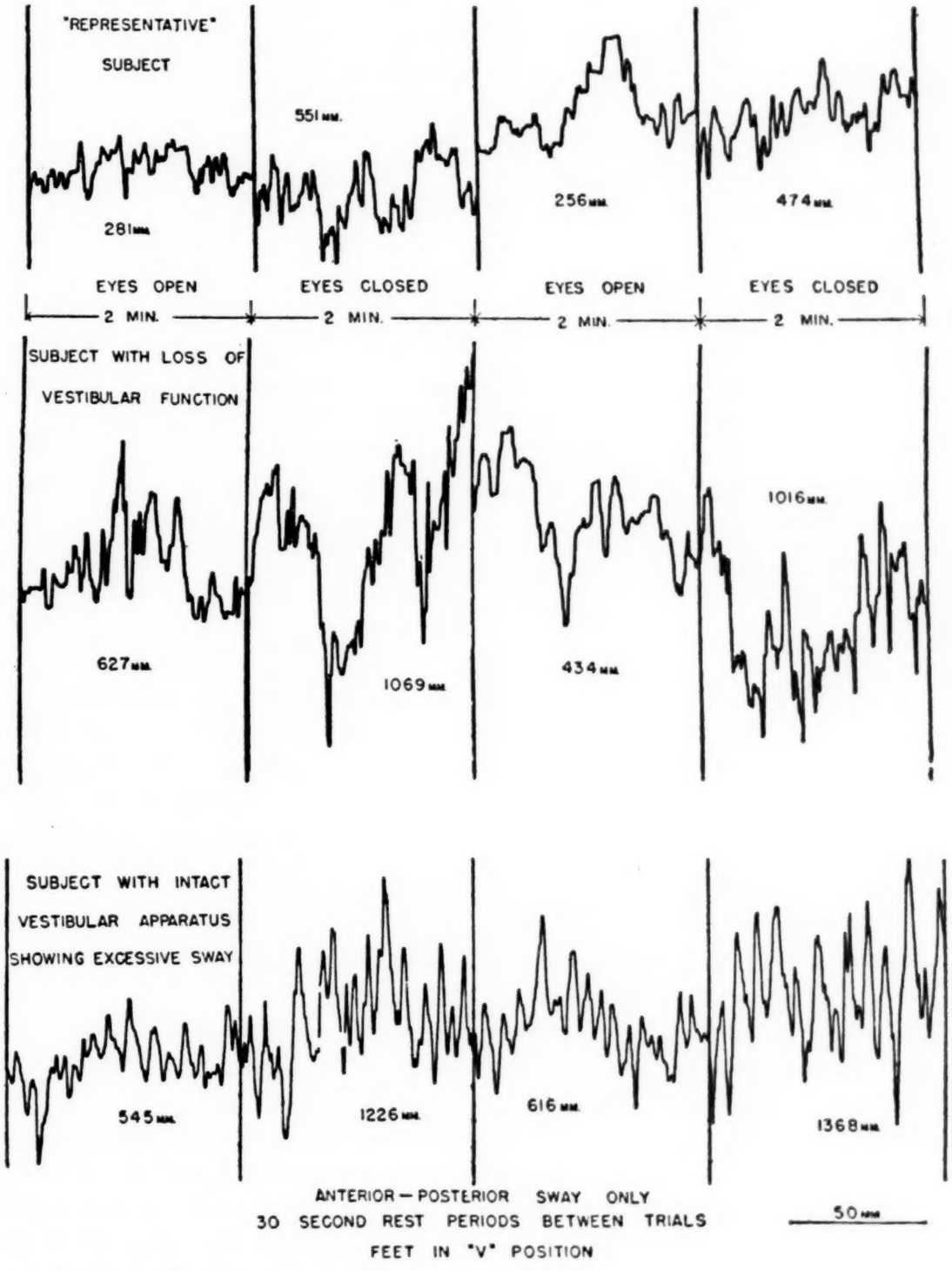

FIG. 1. Comparison of ataxiagraph records of an *S* having no vestibular function with records of normal *Ss*.

sway. The zero correlation between nystagmus and the ratio of body sway eyes open to eyes closed further supports this conclusion.

Discussion

The question as to what the Barany Chair test really measures may have relevance to these results. Following the line of reasoning of Dohlman it appears that the characteristic of a slow and fast phased nystagmus is associated only with vestibular stimulation (**4**). It is apparently impossible to produce the slow phase through voluntary action. One may assume, therefore, that whenever this type of nystagmus appears, vestibular stimulation exists in some form. The converse need not follow, that the lack of such nystagmus is indicative of the lack of vestibular stimulation. One has only to review the history of the Barany Chair test in the period following the first World War to realize that a shortened nystagmus may be brought about as a result of experience. A modification of the postrotational nystagmus through experience, however, can hardly be attributed to any alteration of the peripheral sense organ.

In naive *S*s the duration of postrotational nystagmus may thus be expected to follow the duration of any vestibular stimulation. This duration, about 20 to 30 sec. in most cases, agrees with the value reported for the duration of the postrotational discharge in a vestibular nerve fiber of a ray, 20 to 30 sec. (**9**). These workers, Lowenstein and Sand, attribute the duration of the postrotational discharge to the time required for the ampullae to regain their original position. This suggests that the Barany Chair tests measure indirectly the time required for the ampullae to come to rest after movement induced by acceleration. Higher nervous centers play a minor role in the mediation of this effect in the naive *S*, but may exert an important inhibiting influence in experienced *S*s.

Summary and Conclusions

Observations of body-sway and rail-walking tests were made on a 19 year old male who had lost all VIII nerve functions (vestibular) following an attack of acute meningococcus meningitis. The existence of the vestibular defect was established by complete absence of response to the caloric and Barany Chair tests.

This *S* manifested marked body sway during the first trial period. He did, however, maintain his balance standing erect with eyes open and with eyes closed. One month later this *S* displayed improvement in his postural control so that the record would not be categorized as pathological. During neither of the sessions could the *S* score above zero on the rail-walking test.

Postrotational nystagmus time and body-sway measurements were made on 45 male *Ss*. None of the correlation coefficients obtained between body-sway measurements, eyes open or closed, and nystagmus time were significantly greater than zero.

The findings of this study are interpreted as indicating that man may maintain stable posture despite loss of vestibular function, and that measurements of body sway cannot be used to detect vestibular defects. Postural defects may occur following the loss of vestibular functions, but the defect is soon compensated for. The lack of correlation between postrotational nystagmus time and body sway is further indication of the lack of complete dependence of posture on vestibular functions, or at least on those functions reflected in nystagmus. Superficially it would seem that body-sway measurements were indicative of the adequacy of integration by the cerebellum of sensory cues arriving from many sources, among which those from the labyrinth are not the most important.

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THE RELATION OF SPEED OF LEARNING TO AMOUNT RETAINED AND TO REMINISCENCE

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In a recent paper (**6**), Leavitt and Schlosberg reported an experiment designed to study the relative retention of verbal and of motor materials. Fortunately the design of the experiment was such that a further treatment of the data shed light on two additional problems, (1) the problem of the relation of speed of learning to the amount of material retained, and (2) the relation between absolute and relative amounts of reminiscence shown by individual *S*s. It is to the first of these two problems that primary consideration will be given in this paper.

The procedure used to obtain the data for the present analysis is presented in detail elsewhere (**6**). Briefly, four groups of 12 *S*s each were given 10 30-sec. trials on (1) a list of 15 nonsense syllables, and (2) a modified Koerth pursuit rotor. The four groups were recalled for retention tests after 1, 7, 28, and 70 days respectively, a different group returning after each interval. Scoring was in terms of the number of correct anticipations for the nonsense syllables, and in terms of total duration of target contact for the pursuit rotor.

The Problem

There is almost universal agreement among investigators (**3, 4, 5, 8**) that the slow learner retains less of what he has learned than does the fast learner. The results are the same whether practice is continued to a given criterion of mastery, or to a given time limit. To the writer's knowledge one of the very few studies that is at all equivocal is one of Luh (**7**). Like the great majority of investigators, Luh had concluded that the slower learner was probably the poorer retainer, but he noted also that "with the recognition method, and possibly also reconstruction, the correlation between speed of learning and the amount of retention tends to change from positive to negative" (p. 81), with the passage of time. Thus the learning-retention relationship might not be so clearcut as the earlier experiments, using short retention periods, would lead one to believe.

Results

In the present case our measures of retention were neither recognition nor reconstruction, but our results are similar to Luh's.

From Table I, below, it will be seen that for both materials, the nonsense syllables and the pursuit rotor, the rank order correlations between score on the last learning trial and score on the first relearning trial pass from positive to negative as the length of the intertest period increases. Although not all of the individual correlations can be considered significant, the consistency of the trend is apparent. Taking the individual correlations for what they may be worth, our findings, like those of most other researchers, are of a high positive learning-retention relationship *after short intervals*. But as the duration of the retention period is extended, the correlations decrease through zero to a negative value.

TABLE I

RANK ORDER CORRELATIONS BETWEEN SCORE ON LAST LEARNING TRIAL AND SCORE ON FIRST RELEARNING TRIAL

	1 day	7 days	28 days	70 days
Nonsense	.84±.05*	.67±.10	−.26±.23	−.17±.25
Pursuit	.54±.14	−.06±.29	−.68±.10	−.73±.08

* Standard errors.

The prediction to be made from Table I is simply that the fast learner will retain more material after short intervals than will the slow learner. As the period between learning and relearning increases, the superiority, in terms of amount of material retained, shifts from the fast to the slow *S*.

To approach the problem from a slightly different angle, consider the rank order correlations in Table II. Here the correlations are between amount learned and *relative* amount retained. The score on the first relearning trial has been converted into percent of the score of the same *S* on his last learning trial.

TABLE II

RANK ORDER CORRELATIONS BETWEEN SCORE ON LAST LEARNING TRIAL AND RELATIVE SCORE ON FIRST RELEARNING TRIAL

	1 day	7 days	28 days	70 days
Nonsense	.08±.28	.24±.23	−.45±.17	−.40±.18
Pursuit	.24±.23	−.01±.30	−.46±.16	−.41±.18

Relatively, too, the fast learner, after short intervals, tends to retain more than the slow learner. But again, at longer intervals, the trend is reversed and the fast learner retains a smaller proportion of what he had originally learned.

A third method of considering the results lies in savings scores. In Table III the correlations are between scores on the last learning trial and the percent of trials saved in relearning.

TABLE III

RANK ORDER CORRELATIONS BETWEEN SCORE ON LAST LEARNING TRIAL AND PERCENT SAVED IN RELEARNING

	1 day	7 days	28 days	70 days
Nonsense	.04±.29	−.10±.27	−.84±.05	−.87±.04
Pursuit	.37±.19	−.25±.23	−.42±.18	−.42±.18

In this case the finding is that the fast learner, after short intervals, can relearn to his original criterion more rapidly than can the slow learner. Once again, however, the lengthening of the period between learning and relearning is accompanied by a shift in superiority from the fast to the slow learner. After intervals of seven days or more the fast learner requires more trials to relearn than the slow learner.

At this point, before entering into a discussion of results, we should like briefly to consider the second of the two above mentioned problems, the problem of absolute versus relative reminiscence.

In a recent paper (1), Buxton predicted: "With a low degree of mastery few items have risen near enough to the threshold, at the time of the rest interval, to be available for reminiscence; with a high degree of mastery few items are not already above threshold. Both stages of mastery should be inferior in *absolute* amount of reminiscence . . . to moderate mastery. The relative amount of reminiscence . . . might, on the other hand, grow progressively smaller as the initial level of learning rises" (p. 329).

Buxton later tested this hypothesis (2), and his results substantiated it. As original learning increased, he found that the absolute amount of reminiscence tended at first to increase and then to decrease. The amount of reminiscence relative to the amount of material originally learned consistently tended to decrease.

Although Buxton's technique differed in several respects from our own, the results of the present experiment may serve as a partial check and possible source of elaboration of Buxton's findings. Buxton held amount of material to be learned roughly constant, while time spent in learning was a variable. In the present case time spent in learning was held constant. Furthermore, no *S* ever reached 'high' levels of mastery (more than 50 percent of the total possible material) during the original learning period.

Thus far no mention has been made of the occurrence of reminiscence in our results. Actually, *on the pursuit rotor*, 11 of the 12 *S*s

in the one-day group showed reminiscence, i.e., gains in their first relearning trial over the score on their last learning trial. For the seven-day group, 7 of the 12 *Ss* reminisced. We shall limit our analysis to these two groups because these were the two groups in which more than 50 percent of the *Ss* reminisced.

For the one- and seven-day groups retention and reminiscence may be considered practically synonymous. The two are almost synonymous because our measure of retention included the gain which we have chosen to call reminiscence. For example, in Table I above the correlations are between score on the last learning trial and score on the first relearning trial. Score on the first relearning trial is one of our measures of retention. But since this score on the first relearning trial was often a higher score than that obtained by the same *S* on his last learning trial, the score on the first relearning trial also serves as a measure of gain or reminiscence. If we now consider Table I as a table of correlations between amount learned and absolute amount reminisced, our results are similar to Buxton's. There is a high positive relation between amount learned and amount reminisced after one day (.54), up to moderate levels of mastery. After seven days there is essentially no correlation (− .06).

Similarly, if Table II is considered, what was previously a set of correlations between amount learned and relative amount retained is now a set of correlations between amount learned and relative amount reminisced. But this time the findings do not agree with Buxton's. Instead of a negative correlation indicating that reminiscence is decreasing as the learning level rises, we again find a positive correlation, indicating an increase in percent reminiscence with an increase in level of learning. For the one-day group the correlation is .24; for the seven-day group there is again essentially no correlation, − .01.

Inasmuch as 11 out of 12 *Ss* reminisced, and inasmuch as both absolute and relative retention show a positive relation to original learning, it follows that there is a positive relation between original learning and pure absolute reminiscence.

Finally, if the correlations between absolute and relative reminiscence are determined, they are found to be .91 ± .03 for the one-day group, and .83 ± .06 for the seven-day group.

Before leaving the problem of reminiscence it may be of some value again to note that, although few *Ss* reminisced after intervals of more than seven days, the majority of those who did reminisce after those intervals had original learning scores below the medians of their respective groups. Of the 24 *Ss* at the two longest intervals, 11 showed some reminiscence. Of these 11 *Ss*, 8 had learning scores below their group medians.

Discussion

No final attempt to explain the findings outlined above will be offered at this time. We shall content ourselves with suggesting a few possibilities for explanation, and with pointing out also that no completely satisfactory explanation has ever been offered for those findings which do not agree with ours.

As possible bases of understanding of the relationship between speed of learning and amount of retention the following may be considered:

(1) Overlearning. It may well have been true that the slower *S*s, having learned less, learned it better than did the faster ones. Such an hypothesis would account for the long term superiority of the slower *S*s on the serial task, nonsense syllables. It would not serve to explain the results with the pursuit rotor, nor would it shed much light on the short term superiority, especially the superiority in *relative* retention and reminiscence, for the faster *S*s. This short term success of the faster *S*s would be difficult to explain in terms of overlearning even if it were admitted that interfering tendencies, or fading of weak traces, did not effectively begin until after several days. How could an overlearning hypothesis account for the faster learners' *relatively* greater retention and *relatively* greater reminiscence after an interval of one day?

(2) The negative correlations may be a function of a floor set on learning. As Gillette (**3**) puts it, the slow learner is at an advantage in that, having learned less, he has less to forget. On the pursuit rotor the slow learner's advantage is particularly great; he needs only a single lucky period of contact during his relearning trials in order to equal or surpass his original score. The situation may demonstrate another example of the statistician's 'regression toward the mean.'

(3) Differential forgetting theory, as espoused by McGeoch (**8**), is a possible source of explanation. Actually McGeoch did not seem to apply his differential forgetting hypothesis to this particular problem. Instead, he simply wrote: "This high positive relation between individual scores in learning and retention is to be expected, of course, from the fact that learning and retention are continuing processes. . . The introduction of a relatively long interval between measurements should not greatly alter this relation. It seems then that the 'slow' learner gains no retentive advantage from his slowness and the 'fast' learner is at no disadvantage from his fastness" (p. 388). It would seem, however, that differences in the rate at which correct and incorrect responses are forgotten might very well result in discrepancies between short interval and long interval learning-

retention relationships. If the fast learner has piled up many interfering tendencies as well as correct responses, and if the interferences fade at a different rate from the correct responses, one might certainly expect that time would be a critical variable in the problem.

(4) Since the *S*s had some knowledge of their relative standing there may have been motivational changes taking place between the learning and relearning periods. But again, why the shift in superiority with the lengthened interval?

(5) Any final answer must, it would seem, be in terms of some active process or combination of processes which serve either (*a*) to cause a rapid loss of what the faster learners have acquired, or (*b*) to cause a gradual gain over and above what the slower learners originally reproduced, or (*c*) both. A satisfactory basis for understanding the findings may lie in some sort of a decrement hypothesis (**6**). Such an hypothesis would assume that reproduction is not a true measure of learning, but that the slower 'learners' are in reality just the poorer reproducers. The decrement between the amount of material actually learned and the amount reproduced would be greatest for the slowest learners and would be gradually dissipated. Taking into account the simultaneous process of forgetting, long term gains by the poorer 'learners' would be expected, while at short intervals, before forgetting has set in, the faster learner might well retain more material than the slower one.

Although such an hypothesis may account for the change from positive to zero correlations, it is difficult to see how it could be made to fit the continued decline of the correlations from zero through negative values. Moreover a decrement hypothesis, in its present form at least, could not very well account for the results with nonsense syllables where no reminiscence occurred.

No one of the above suggestions completely fits all the facts. But again it may be pointed out that the evidence for one of psychology's most widely accepted dogmas, i.e., that the faster learner is the better retainer, is neither conclusive nor supported on any entirely satisfactory theoretical grounds. The generalization seems at the most to be only partially true. For the immediate present at least, we are satisfied to reopen a question which may have been inopportunely closed.

Summary

Four groups of 12 *S*s each were given 10 30-sec. trials to learn a list of 15 nonsense syllables, and a similar 10-trial session on a pursuit rotor. The retention of each material was tested after 1, 7, 28, and 70 days, one of the four groups returning after each interval.

It was found that:

(1) The rank order correlations between amount learned and amount retained change from positive to negative for both materials as the retention interval increases. This generalization holds whether we consider absolute amount retained, amount retained relative to original score, or savings.

(2) The correlation between absolute and relative amounts of reminiscence on the pursuit rotor is high and positive.

(3) Fast learners show the greatest absolute amount of reminiscence and also the greatest amount of reminiscence relative to their original scores, when the retention interval is short.

(4) After intervals of 28 days and longer, only the slower tended to show any reminiscence on the pursuit rotor.

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VALUE OF WRONG RESPONSES IN INDUCTIVE REASONING

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When an individual formulates a hypothesis, acts upon that hypothesis, and discovers that he has been successful in solving his problem, he has a tendency to believe that his hypothesis was correct. Scientists realize that such a conclusion may be in error and are careful to set up experimental controls to verify positive findings. For example, suppose that one entertains the hypothesis that a wound may be cured by applying ointment to the knife which made the wound. Should a great proportion of the wounds (or, indeed, all of them) heal following such anointings of the knives, these results could not be used as evidence that the treatment was effective. It would be necessary to use a control group of individuals with similar wounds and to apply no ointment to the knives which produced the wounds in this group. Then, if those in the control group who received no knife anointings died, whereas those in the experimental group who did receive knife anointings recovered, the hypothesis would thereby be supported. Clearly, it is not the evidence that the wounds are cured which makes the hypothesis tenable. It is *only* when the evidence of positive cures is supported by evidence that the wounds will not heal when the ointment is not applied that the hypothesis gains support. That is to say, negative instances are essential for scientific conclusions; the scientist must have failures. Indeed, failures in science are more illuminating than are successes.

But does the ordinary man think in this manner? Is he not likely to believe that success in solving a problem means that he performed correctly? He does not feel impelled to hunt for failure in order to convince himself that he was correct. Getting the answer is taken as evidence that he secured it in the proper manner. He tends to become impatient if someone suggests that his success may have been an accident or that it might have been due to some unknown factor which chanced to be working at the right moment.

If the above interpretation of ordinary reasoning is correct, would it not follow that experiences which are uniformly successful would be less helpful in teaching a person to think critically than experiences in which successes were restricted and in which there would be more

opportunities to experience significant failures? The present experiment was designed to test this hypothesis.

In order to develop an experimental procedure which would throw light on this question, several requirements seemed to be essential:

1. The *S* should be confronted with a relatively simple situation which would permit the adoption of several hypotheses, each equally tenable, but which could be verified only by actual trial.

2. The problem should be of such a nature that one *S* could be made to succeed no matter what hypothesis he tried, whereas another *S* could be restricted to a specific solution and made to experience failure should he not guess correctly. The individual in the restricted situation would thus be exposed to the possibility of critical failures, whereas the one in the free situation would be relatively free from failure.

3. The effect of such a difference in training should be determined by comparing the scores of each individual in a test which was of the same nature as the problem material used in the practice.

Description of the Experiment

Twenty-seven three by five in. cards were prepared, each card containing three forms (a square, a circle, and a triangle), each form on any card being of a color (red, yellow, or green) different from that of the other two. Both form and color changed positions in the successive cards. Five such cards are illustrated in Fig. 1. The order of presentation was first made by

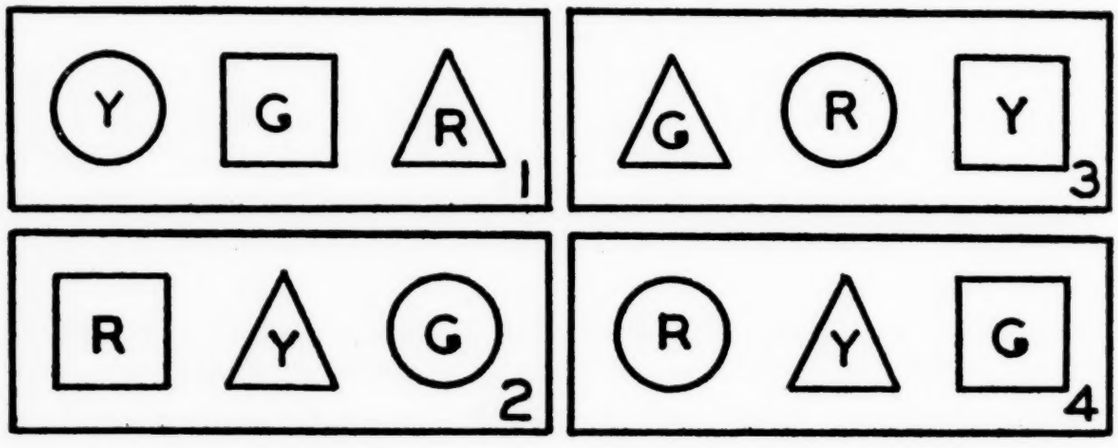

Fig. 1. A representative sample of a sequence of exposures showing how form and color appeared in different positions and in varying combinations. R = red, Y = yellow, G = green.

chance, but with rearrangements so that the same form and color would not appear in the same position in successive presentations.

An apparatus was made which, as far as the *S* could discern, consisted merely of three buttons arranged in a horizontal row in front of him. These buttons were attached to switching mechanisms hidden from the *S*, but under the easy control of the *E*. By the proper manipulation of buttons on his side of the apparatus, the *E* could set the apparatus so that only a certain button would cause a bell to ring, or so that either of two buttons would cause the bell to ring, or so that the bell would ring no matter which button the *S* pressed.

The following instructions were read to each *S* before he began the experiment:

"You see these three buttons. When the correct one is pressed a bell will ring, so. [*E* demonstrates by pressing one button.] But I have a device back here by means of which I can change the correct button. Watch. When I press this one the bell will ring. [*E* demonstrates.] But now, after I have changed the apparatus, it no longer rings the bell; but this one does. [*E* demonstrates again by pushing another button.]

"Now, I want you to play a little game with me. I will hold up a number of cards in succession, like this one. [A sample card is exposed.] Each one of these cards will contain three figures. From these figures you will get cues as to which button will make the bell ring. At first you will have no idea what the cue is, but you will push a button anyway. If the bell rings, you will know that the figure on the card which has the same relative position as the button you press contains the cue which makes the bell ring. If the bell does not ring when you press a button, you will know that the corresponding figure on the card does not contain the necessary cue. After you have pressed a button, I will take the card away whether you responded correctly or not, and will show you another to which you will respond. I will continue putting up cards with different arrangements of cues and you will push just one button each time until you learn to press the right button each time. Use your forefinger so that I can see clearly which button you pressed. Remember, you press but one button for each card regardless of whether your response makes the bell ring or not. When I start a new series I will tell you. The new series may or may not use a different cue from the one in the preceding series. I will simply say 'This is another series,' and you will begin again to find the correct cue for that series."

It should be noted that these instructions say nothing about the nature of the cues which the *S* is to extract from the total situation—no mention is made of form or color. The *S* is merely told that if he presses a certain button, say the middle one, and the bell rings, he will know that the figure in the middle of the card contains the correct cue for the ringing of the bell, and that if it does not ring, he will know that the figure in the middle position does not contain the correct cue.

Suppose, for example, that the card containing the three figures displayed in the first section of Fig. 1 is exposed to the *S*. He will have no indication which of the three buttons he should press. He can only guess. Suppose he presses the one to his left and the bell rings. He will thereby be informed that the bell rings when he presses the key corresponding to a yellow circle The card is removed and the second card, illustrated in the second section of Fig. 1, is shown. This card has no yellow circle on it; but it does contain a green circle and a yellow triangle. Suppose he presses the key corresponding to the green circle and the bell rings. Since the bell rang when he pressed the key corresponding to a yellow circle on the first trial, and since it also rang when he pressed the key corresponding to a green circle on the second trial, he is likely to accept the circle as the correct cue. When the third card is exposed he is likely to press the middle button corresponding to the red circle. That is to say, if the *E* begins a series of exposures after having decided to make the circle the correct cue for that series, the *S*, if luck is with him for two trials, may learn this cue without ever making a single mistake.

In case the *S*'s response does not cause the bell to ring, his problem becomes a little more complicated. For example, suppose when he presses the button to his left on the presentation of the first card, the bell does not ring because the *E* has decided on green as the essential cue. If the *S* profits by this experience, he may avoid yellowness and roundness on the exposure of the second card and press the left-hand button again. Again the bell will not ring, and he will have learned something more; namely that redness and squareness are ineffective. He still has untried a green color and a triangular form. When the third card appears both of these cues happen to come together; he can press the left-hand button, corresponding to the green triangle, and the bell will ring, but he has learned nothing new. Therefore, on the fourth card he still must guess. Should his interest have been centered on form cues in the earlier trials, he would likely select the middle button and fail to make the bell ring. Should it have been centered on colors, he would probably select the green, press the right-hand button and the bell would ring. Either a failure or a success should serve equally well on the fourth card to lead him to the proper conclusion.

These illustrations exemplify the kinds of situations which could arise when the *E* selects a certain cue for each series. The reader can test the complexity of various situations by setting different cues and following the consequences of pushing different buttons.

Now, let us describe what happens when the *S* is made to succeed in ringing the bell no matter what cue he selects. The same instructions are given, but the *E* decides in advance

that he will make the *S* succeed in ringing the bell no matter which button he presses. Suppose that he presses the middle button on the first exposure. The bell rings and the *S* can accept this as evidence that the green square is the correct cue. On the second exposure he sees no green square; instead there is a red square and a green circle. He must guess between these two. No matter which one he chooses, he will again be successful. If he presses the left-hand button, he thereby is likely to become convinced that squareness is the correct cue and probably will continue to press the button corresponding to the square throughout the rest of the series. If he presses the right-hand button, he will probably believe that greenness is the cue and continue to press the button corresponding to the green color. He will have succeeded but he will not have used any inductive reasoning. He may think he was lucky, or that he was unusually clever, but the truth is that he has been deprived of the opportunity to use his reasoning abilities through the beneficence of an *E* who ordained that he should succeed at any cost.

The 42 *S*s in the experiment were separated into two groups, the restricted hypothesis group and the free hypothesis group. They were all students in psychology and, as they volunteered, a schedule of appointments was made. The odd individuals in this schedule were put into one group and the even ones in the second group.

Both of the groups were given 15 series of exposures, each series containing 10 different card presentations. Thus, each made 150 responses in the entire experiment. At the end of each series of 10 exposures, all were told, "This is another series." Nothing was said to them about any such thing as restricted or free hypotheses, about form or color, and they had no way of knowing whether a series was a practice series or a test series. From the *S*'s viewpoint, he merely had 15 series of exposures, in some of which he seemed to be lucky and in others not so lucky in his selection of the correct cue.

For the restricted hypothesis group the *E* decided in advance what the correct cue for each series would be, and arranged the apparatus for each exposure so that only the key corresponding to that cue would be effective. This prearrangement of cues was determined by chance.

For the free hypothesis group, quite a different situation was created. For the first two series the *E* arranged the apparatus so that the pressure of any key would cause the bell to ring. For these two series the *S* succeeded no matter which cue he selected or which button he pressed. Nevertheless, every third series with the free hypothesis group was made into a restricted hypothesis situation, so that the problem for an individual in each group was the same in series 3, 6, 9, 12, and 15. To be sure, these test series gave an individual in the unrestricted hypothesis group some experience with the problem of finding the correct cue when there was but one possible correct cue and he also experienced some failures in working with these five test series. But he had only five such series as compared with 15 for an *S* in the restricted group. The thesis underlying the experiment was that the easy success of a *S* in the unrestricted group would render him less competent in working out the correct cue on the five test series interspersed with the easy series, when compared with the ability of an individual who was limited to one cue throughout.

Results

The comparison of scores made by the two groups is exhibited in Table I. The scores were obtained by taking the total number of errors made in series 3, 6, 9, 12, and 15 for each group. Thus, a score of five means that the *S* made an average of one error for each of the test series of 10 presentations; a score of 35 means that the *S* averaged seven errors for each of the test series.

The scores for the unrestricted hypothesis group ranged from 6 to 35, with an average of 16.33; whereas those for the restricted hypothesis group ranged from 4 to 25, with an average of 10.10. The difference between the two groups is highly significant, the *t*-value of 2.93 with 40 degrees of freedom indicating that there is less than one chance in 100 that the obtained difference would have resulted from chance.

TABLE I

COMPARISON OF TOTAL ERRORS MADE ON FIVE TEST SERIES BY INDIVIDUALS IN THE TWO GROUPS

	Individual scores with unrestricted hypothesis		Individual scores with restricted hypothesis	
	6		4	
	7		5	
	8		6	
	10		6	
	10		7	
	12		8	
	12		8	
	12		8	
	13		9	
	14		9	
	14		9	
	14		9	
	15		10	
	15		10	
	16		11	
	19		12	
	23		13	
	24		13	
	30		15	
	34		15	
	35		25	
Average	16.33		10.10	
Sigma	8.63		4.57	
		Difference between means		6.23
		t		2.93
		Significance		$P < .01$

DISCUSSION

Some additional information was gleaned from the way in which certain *S*s responded to the experiment. It should be recognized that it was perfectly possible for an *S* in the restricted hypothesis group to guess correctly and thus get no profit from failure, and this happened in quite a number of series. But this was the exception, whereas, in the unrestricted hypothesis group, the *S*s all went through the 10 series of 10 responses each without making an error. The bell always rang because the apparatus was set to make it ring no matter which button they pressed.

The interesting feature was the way in which most of the *S*s reacted when they succeeded so easily. Some remarked, "Boy, am I lucky!" Others would settle down with a self-satisfied air and press the button corresponding to a specific form or color, obviously gloating over a success which they had not earned. Furthermore, when they shifted to another cue at the beginning of a new series, it was clear that they were relying solely on guessing. For example, an *S* might say, after he had succeeded on the first two reactions of a series, "Oh, red is the cue." Then, when a new series would be announced, he might say, "Guess I'll try yellow this time." Since, of course, yellow would make the bell ring, he would remark, "Right

again, am I good!" On the third series, he might say, "Well, this time I'll try green." Since this would be a test series, he might be wrong, but he would continue to guess, trying one cue after another until he chanced to hit the right one. To be sure, some of the *Ss* in the unrestricted group did understand, and use some inductive reasoning in the five test series which they went through, but the *Ss* in the restricted group learned better to analyze the situation and to depend more upon inductive procedures.

These results seem to substantiate the original hypothesis in so far as this specific experimental setting operates. Success tended to inhibit the efficient use of inductive processes, whereas failure instigated a critical analysis of the significance of both failures and successes.

Summary

This experiment was designed to test the hypothesis that failures to solve a problem foster inductive reasoning more than do immediate and uniform successes.

Ss were confronted with the problem of discovering which of six cues to follow in order to make a bell ring. In one group (called the restricted hypothesis group) the cue which would make the bell ring was predetermined by the *E*. In another group (called the unrestricted hypothesis group) success followed the use of any cue by the *S*. Interspersed throughout the experiment were test series to determine how well the *Ss* in both groups could discover a predetermined cue.

It was found that the individuals in the restricted hypothesis group profited by the mistakes they made in hunting for the correct cue and surpassed, on the test series, the records made by individuals in the unrestricted group. The difference between the groups was statistically significant and lends support to the original thesis of the experiment.

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A COMPARISON OF THE NAVY ADAPTOMETER TEST AND THE COLUMBIA MOTION ACUITY TEST *

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Introduction

The aim of the present study was to make a comparison of the scores secured on the Navy Radium Plaque Adaptometer with threshold values obtained on the Columbia University Motion Test. The one is a test of scotopic form acuity, and the other of scotopic motion acuity. This research is a continuation of the work recently reported from this laboratory. The first report (3) on this general project dealt with the standardization of the motion acuity test. The second report, published in two forms (2, 4), was a study of individual differences in scotopic motion acuity and in photopic form acuity (Snellen Test).

The Navy Adaptometer was devised by the Bureau of Medicine and Surgery for screening purposes in connection with the selection of night-lookouts. Although the apparatus was already in use by the Navy, it seemed desirable to compare the results secured on the Adaptometer (form) and on our own device (motion). An extension of the original project to make such a check-up was made on November 1, 1943, to run for a period of six months.

Method and Procedure

In this section a brief description is given of the *Ss*, the apparatus, and the procedure used in testing.

Selection of Ss

The 100 *Ss* were selected from Columbia College (25) and Barnard College (75) students. They were all between the ages of 17 and 25, and reported no history of visual defect. The selection was made in a preliminary interview, at which a Snellen Index of 20/20 or better in each eye was required. A session of about two hours was required to give both tests (Adaptometer and Motion Acuity). The *Ss* were paid $1.00 each at the end of the period.

Apparatus

The group was tested on both the Adaptometer and Motion Acuity apparatus, and a brief description of these will be necessary.

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* The work described in this paper was done under a contract recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Columbia University.

[1] The senior author was Responsible Investigator, and the junior author Professional Scientific Assistant on this project (OEM cmr-264).

Thanks are due to Mr. Donald Gordon and to Mrs. Shirley A. Montroll for aid in the statistical treatment of the results.

A. Radium plaque adaptometer.—The instrument used here was the Navy Adaptometer (Device 9-B-4). The radium plaque, produced by the U. S. Radium Corporation, gave a brightness level of 3.94 log. micro-micro-lamberts, when reduced by an Eastman Kodak neutral filter of 0.6 density. The plaque was circular in shape and subtended an angle of 5 degrees at 5 feet. The stimulus figure was a Snellen 'T,' subtending an angle of 3 degrees at 5 feet. A red fixation point was placed 7 degrees above the center of the 'T,' which was jet-black.

The standard testing procedure, as given in the *Maintenance and Instruction Manual* supplied with the instrument, was carefully followed.[2] In administering the test, the *S* was first dark adapted by means of the Navy red dark adaptor goggles for 25 min., followed by 5 min. in the dark test room. The *S* was then seated in a chair, adjusted to eye level at a distance of 5 feet from the stimulus. The usual 5 practice trials were given without the filter (brightness level 4.54 log. micro-micro-lamberts) to train the *S*s in fixating and making judgments. The test proper consisted of 50 presentations of the 'T,' randomized as to position. The positions were right, left, up and down. The *S* was required to report the direction in which the 'T' was pointing, when it was regarded as an airplane silhouette. Three types of judgment were recorded on the standard test record blank: (1) right, (2) wrong, and (3) 'don't know' or 'can't see.'

The Adaptometer score (standard) was obtained by multiplying the number of correct responses by three, and subtracting the number of wrong responses from this. No attention was paid to the judgments: 'don't know' or 'can't see.' This method of scoring involved the usual principle of treating multiple-choice items in order to eliminate chance.

Another method of scoring is possible, which gives what we have called the 'raw' score. This is obtained by simply taking the number of correct judgments made by an *S* on the 50 presentations of the stimulus. A comparison of these two types of scores will be made in a later section.

The Adaptometer is a fairly reliable instrument. The test-retest reliability, based on 100 *S*s, has been reported as .70. More recently, Peckham and Verplanck (1) determined the reliability on a larger group. They found that the test-retest reliability, based on 500 *S*s, was r (cos.) = 0.78 from a pass-fail, test-retest double dichotomy. In the present experiment, the split-half reliability was determined for both standard score and raw score on 100 *S*s. This was done by comparing the scores on the first 25 trials with the scores on the second 25 trials in each case. The correlation coefficient (uncorrected) was .82±.02 for the standard score, and .80±.02 for the raw score. When these were corrected by the Spearman-Brown formula they were raised to .90±.01 and .89±.01 respectively. The distribution of the standard Adaptometer scores, based on 100 *S*s, was fairly normal.[3]

B. Motion acuity test.—The apparatus for studying motion acuity developed in the Columbia University laboratory has been described and illustrated in earlier reports (2, 3, 4). It will suffice here merely to call attention to specific changes made in the apparatus for the present study.

The stimulus conditions were precisely the same as in the Adaptometer, except for the fact that rotation was introduced in order to study motion acuity. The radium plaque, with a figure 'T,' was secured from the Navy stock. This, together with the proper neutral filter (0.6 density), was mounted on the driving shaft of the motion apparatus. This entire set-up was enclosed in a light-tight box, provided with a sliding shutter. Both box and shutter were covered with several coats of dull black paint. The stimulus could be rotated in either the clock-wise or counter clock-wise direction. It was located 5 feet from the *S* in direct line of vision. The fixation point was the same in size, illumination and position as that employed in the Adaptometer. The materials for the fixation point were secured from the Polaroid Corporation. As in the Adaptometer, binocular vision was used.

The degree of dark-adaptation was the same as in the Adaptometer test. The motion acuity test was given immediately after the Adaptometer test, the *S* being merely shifted to the new apparatus in the dark-room. The *S* was allowed to sit in the dark cubicle of the motion apparatus for 5 min. before the test began.

The aim of the motion acuity test was to determine the motion perception threshold of each *S*. The method of adjustment, which seems to be the most natural and accurate, was employed as follows: (1) the general speed level of the stimulus (rotating plaque) was set well

[2] This procedure has since been changed in certain details by the Navy Department.

[3] A further analysis of the Adaptometer scores will be found in the final report covering Project OEMcmr-264 (Supplement No. 3), April 30, 1944.

above the threshold by the *E*, (2) the *S* then decreased the stimulus speed (rheostat control) in large steps to a point below the threshold rate, and (3) the speed was then increased by the *S* in small steps up to the threshold value, as defined by the criterion used.

A high criterion for motion perception was used in order to avoid doubtful judgments and inconsistencies. The threshold value was defined as the speed at which the *S* could see definite motion with absolute certainty. Thus the factors of inference and suggestion were avoided. The standard requirement was that the *S* be able to make a judgment of good motion in three successive exposures at the accepted threshold speed. It is likely that the threshold values secured by the use of this criterion were somewhat higher than the absolute threshold.

It was necessary to expose the stimulus for two sec. instead of the one sec. allowed in the Adaptometer test. This is due to the fact that judgments of motion require a longer time than judgments of form, i.e., the stimulus must remain visible for a longer time. In short exposures, the stimulus tends to 'wash-out,' before a motion judgment can be made.[4] However, an exposure period of two sec. was found to be sufficient for the radium plaque type of stimulus.

The threshold speed, in terms of sec. for 30 degrees of central angle, was read directly from a chronoscope connected to the shaft bearing the stimulus. Three independent determinations of the threshold value were made on each *S*. The range of speed for a complete revolution of the plaque was from about 144 sec. (best *S*) to about 6 sec. (worst *S*). This can be stated in terms of speed for rotation of the radium plaque through an angular distance of 30 degrees, as read from the timing disc. The range in speed was from 12.64 sec./30 deg. to 0.62 sec./30 deg., with a median speed of 3.81 sec./30 deg.

In the Adaptometer test, the *S*s reported that the 'T' was easier to perceive in some positions than in others. As a rule, the right or left positions gave a somewhat clearer form perception than the up and down positions. In order to rule out this factor in the motion test, 30 presentations of the stimulus in randomized positions were given at the final threshold speed. In this series, the direction of movement (clock-wise, counter clock-wise) of the stimulus was also randomized. Blank tests (no motion) were introduced from time to time. A score of 27 correct out of 30 judgments was required in this final series. This means that the threshold values determined are independent of both direction of movement and position of the stimulus figure.

The motion acuity test shows an extremely high index of reliability. The reliability was determined by two somewhat different methods. Since three independent determinations of the threshold value were made, it was possible to correlate the values for the 1st and 2nd, 1st and 3rd, and 2nd and 3rd determinations for the group of 100 *S*s. The product moment correlations so obtained ranged from .97 to .99, with a PE of .01. The second method of determining the reliability involved averaging the correlation coefficients after converting them into *z-scores*. The average thus secured was .98 ± .01. This is the best estimate obtained of the reliability of the three determinations. The unusually high reliability of the motion acuity test is doubtless due to the careful standardization of apparatus and procedure, and to the use of a high criterion of certainty in making judgments of motion.

Results

The results secured may be analyzed with respect to various factors by the use of the usual correlational techniques. As already indicated, each of the 100 *S*s was given a photopic test (Snellen) and two scotopic tests (form, motion). This made it possible for us to compare directly the indices of various visual functions.

Snellen Test

As already indicated, only those *S*s were included who showed a Snellen Index of 20/20 or better in each eye. Since the form and motion tests were both binocular, it was necessary to use a single Snellen Index in correlating. The Snellen score of the stronger eye

[4] For detailed information on this point, see the earlier reports (2, 3, 4).

was used here, since it is commonly assumed that binocular vision approximates the level of the better eye.

The biserial correlation technique was employed. This involved arranging the individuals into two Snellen categories (20/20, and 20/15 or better). The Adaptometer scores (standard) and the motion acuity threshold values were ranked in separate series. The correlations obtained are indicated below:

Snellen-Adaptometer	$r_{bis} = .02 \pm .09$
Snellen-Motion	$r_{bis} = .04 \pm .08$

Both correlations are approximately zero. In the previous study (4) the biserial correlation between Snellen score and mean motion acuity threshold value on 28 *Ss* was found to be $.07 \pm .10$. It is apparent from these correlations that there is little, if any, relationship between photopic and scotopic visual functions. At any rate, an individual with a high Snellen score (20/15 or better) is no more likely to have superior scotopic acuity (form, motion) than an individual with an average Snellen score (20/20). It is clear, therefore, that a special scotopic test, for either form or motion acuity, is necessary for the proper selection of night-fliers, night-lookouts, scout snipers, etc.

Adaptometer and motion acuity tests

As indicated in an earlier section, the primary aim of this investigation was to compare the results secured on these two tests of scotopic vision (form, motion). The Adaptometer test yielded a standard score and a raw score (number correct). The measures secured on the motion acuity test were threshold values. The correlations between both types of Adaptometer score and the motion acuity threshold value proved to be surprisingly high, as shown below:

Motion—Adaptometer (standard)	$r = .93 \pm .01$
Motion—Adaptometer (raw)	$r = .90 \pm .01$

As will be seen, it makes little difference which of the two types of Adaptometer score is utilized in making the comparison. This finding is further supported by the fact that the product moment correlation between the two types of score (standard, raw) was found to be $.98 \pm .01$.

Comparison of other indices

It seemed desirable to determine the relationship between the motion acuity threshold value and the motion acuity score. In order to do this, it was necessary to set-up the motion apparatus as a test,

along the same lines as that used in the Adaptometer test (**5**). This involved the determination of the median motion acuity threshold value on a group of 100 *Ss*, and then using this speed (3.81 sec./30 deg. central angle) as the test standard. The test was similar to that of the Adaptometer: 50 presentations of the stimulus at this speed, with blanks (no motion) interspersed, were given to each of 25 *Ss*. Judgments of 'motion' or 'no motion' of the stimulus were required. The product moment correlation between the number of correct judgments on this test and the motion acuity threshold value for the group was found to be .85 ± .04. This correlation would doubtless have been considerably higher if a larger number of *Ss* had been available. It is clear, therefore, that the method of testing by the use of a median level is satisfactory.

Since we had obtained test scores (motion), it was possible to compare these with the Adaptometer scores on the group. The test scores (motion) were secured as described above. These were then correlated with the Adaptometer score (standard), and the correlation coefficient was found to be .86 ± .04. The correlation is thus quite high, when the small size of the group is considered.

These results would seem to indicate that the two tests (form, motion) measure much the same thing. They suggest that form and motion perception are highly related visual functions at scotopic levels of illumination. It would appear to make little difference, therefore, which type of test is utilized in the selection of night-operating military personnel. Inasmuch as the Adaptometer is already available, our recommendation is that it be used for screening purposes in this field. We see no need for the development of a motion acuity apparatus, either as a substitute for the Adaptometer or to be used as an additional device in selection.

Summary

This study is a continuation of the investigation of scotopic vision covered in the report of August 6, 1943 (CAM No. 182). This extension, which ran from November 1, 1943, to April 30, 1944, is concerned with a check-up of the Navy Adaptometer against the Motion Acuity Test, devised in the Columbia University Laboratory.

A group of 100 *Ss*, between the ages of 17 and 25, and with a Snellen Index of 20/20 or better, were tested on the Navy Adaptometer and on the Columbia Motion Acuity Apparatus. The standard radium plaque of the Adaptometer, set for a brightness level of 3.94 log. micro-micro-lamberts, was used in both tests. The stimulus figure was a Snellen 'T,' subtending an angle of 3 degrees at 5 feet, and the fixation point was 7 degrees above the center of the 'T.'

The following facts and conclusions are supported by the data obtained:

1. No significant relationship was found between photopic form acuity (Snellen Test) and either scotopic form acuity (Adaptometer) or scotopic motion acuity (Columbia motion apparatus).

2. A high correlation was found between the two scotopic tests (form, motion). The coefficient of correlation between motion threshold values and standard Adaptometer scores was .93 ± .01. Thus, the two tests appear to measure much the same thing. This suggests that form and motion perception are highly related visual functions at scotopic levels of illumination.

3. The reliability of both scotopic tests was high. The Adaptometer gave a split-half reliability coefficient (uncorrected) of .82 ± .02, based on the standard scores. The product-moment correlations, obtained between three independent determinations of the motion threshold, ranged from .97 to .99 ± .01. An average of the correlations, after conversion into *z*-scores, was .98 ± .01.

4. The motion perception apparatus, which had been used in determining threshold values, was set up as a motion perception test along the lines of the Adaptometer test. The median threshold speed for the group was presented 50 times to a group of 25 *S*s. The correlation between motion test score and motion acuity threshold value was .85 ± .04.

5. A correlation of .86 ± .04 was found on the same group between standard Adaptometer score and standard motion perception score.

(Manuscript received July 17, 1944)

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THE EFFECT OF CERTAIN VARIABLES ON VISUAL AND AUDITORY REACTION TIMES

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The d'Arsonval clock has been utilised by many workers for recording reaction times (**10**, **15** and **17**). More or less elaborate pieces of equipment to test the reaction time to light or sound in motor car drivers were designed by Heise and Halporn (**9**), Newman and Fletcher (**13**), DeSilva (**14**), and Frank (**7**). As a result of testing 4000 people, DeSilva found that the average reaction time to a visual stimulus (i.e., the time required to remove the foot from the accelerator and depress the brake) is about 0.44 sec. He stated that quickness in this test is an inborn potential factor and is not improved very much by driving experience. This figure corresponds closely with that reported by Farmer and Chambers (**5**). Frank (**7**) reported the reaction times of men and women to a visual stimulus as 0.6 sec. and 0.8 sec. respectively. The times obtained in traffic studies are much longer than reaction times recorded when keys are pressed by individuals in response to a warning light or sound. Reviewing previous work, Baxter and Travis (**1**) found that the results varied from 0.150 sec. to 0.200 sec. for visual stimuli, and from 0.120 sec. to 0.160 sec. for auditory stimuli in different papers examined. It is quite obvious therefore that the reaction time obtained depends on the apparatus used, and on the conditions of the experiment.

The measurement of the reaction time must involve the manipulation by the *S* of some piece of apparatus and it is to be expected that practice will play a very prominent and important part. Many authors mention no particular precautions taken to eliminate the effects of practice from their results. At the other extreme we find Dodge and Benedict (**4**) who considered reaction times so subject to the effects of practice and other extraneous influences that they regarded this test as valueless in studying the effect of alcohol. Miles (**12**), Jonnard and Maire (**10**), Zwahlen (**17**), and Cheney (**3**) all allowed more or less practice before establishing a normal on which the effect of any added factor could be assessed. Jonnard and Maire (**10**) and Cheney (**3**) succeeded in reaching an 'established normal reaction time' in their *S*s as a result of practice. If this could be done it would be a great advantage in experimental work

on the influence of any additional extraneous factor on the reaction time.

Another variable of importance is that of age. Bellis (**2**) in a study of 150 individuals of various ages found that the shortest times were elicited between the ages of 21 and 30 years, with decrements approaching from earlier and later age groups. Cheney (**3**) agrees with this conclusion.

If the reaction time is proportionate to the intelligence then it is unsuitable as a test to be applied to all grades and classes of the community. Goodenough (**8**) concludes that, in any group of individuals selected at random from a reasonably homogeneous population, the relationship between intelligence and reaction time is very slight.

It is generally accepted that, as the day progresses and the products of metabolism accumulate in the tissue cells, efficiency and speed of performance will decrease, and as a corollary that reaction times will increase. So far as can be ascertained there is no reference in the literature to the influence of fatigue on reaction times, but from the work done by Vernon (**16**) and McDougall and Smith (**11**) on the effect of fatigue on typing it can reasonably be inferred that fatigue may be an important factor in any experiments on reaction times.

There appears to be no evidence available on the effects of the state of the alimentary canal on the reaction time.

It is apparent from a study of the literature that the reaction time depends on the apparatus used, that intelligence plays no part, that fatigue, practice, and age might be important factors requiring consideration, and that the effect of the state of the alimentary canal on the reaction time is quite unknown.

Apparatus

The equipment is designed to be portable and capable of rapid assembly. The main portion of the machine consists of a wooden case 36 in. long by 15 in. broad. In the centre of the box there is a hinged lid with an aperture in it three-quarters of an in. in diameter behind which the lamp is situated. The *S* sits facing the upright board and holding in his hand a bell-push attached to the base board by a length of flex. On the other side of the partition a single stroke bell is screwed to the base, and there are terminals to which leads 12 yards in length can be attached. The operator is isolated from the *S* in order that no intrinsic noises in the apparatus may serve as a warning to the *S* of the imminent appearance of the light signal. The chronoscope, the battery, and the observer's controls are all arranged on a convenient table at a distance from the *S*. The recording instrument used is the d'Arsonval clock, and the wiring of the equipment is designed so that either a visual, or an auditory signal can be selected by the operator. One circuit therefore includes the chronoscope, a selector pear switch, the operator's switch, and the bell and lamp for emitting the signals. Part of the circuit belongs exclusively to the lamp, part to the bell, and part is common to both. An eight volt battery provides the current necessary for starting the hand of the clock, lighting the lamp, and ringing the bell. As one operating switch controls both the signal selected and the chronoscope, the movement of the hand from zero and the emission of the signal are absolutely synchronised. Selection of the appropriate

circuit, according to whether a visual or auditory signal is required, is made by operating a pear switch. There is an independent circuit to the clock including the *S*'s switch and a two volt battery, and completion of this circuit stops the clock. The electrical circuits involved are illustrated in Fig. 1.

Experimental Methods

In all, 178 *S*s were examined. Some recorded only one series of readings while others made up to 21 tests. The men varied in age from 17 to 53 years, and, within these age limits, may be considered a fairly representative sample of the male community. Each experiment consisted of a series of 25 observations in response to each signal from which an average was struck. Records were kept of the number of hours sleep each *S* had had, of the time that had elapsed since he got up, and the time since his last meal. Uniform instructions as to procedure were read to each man.

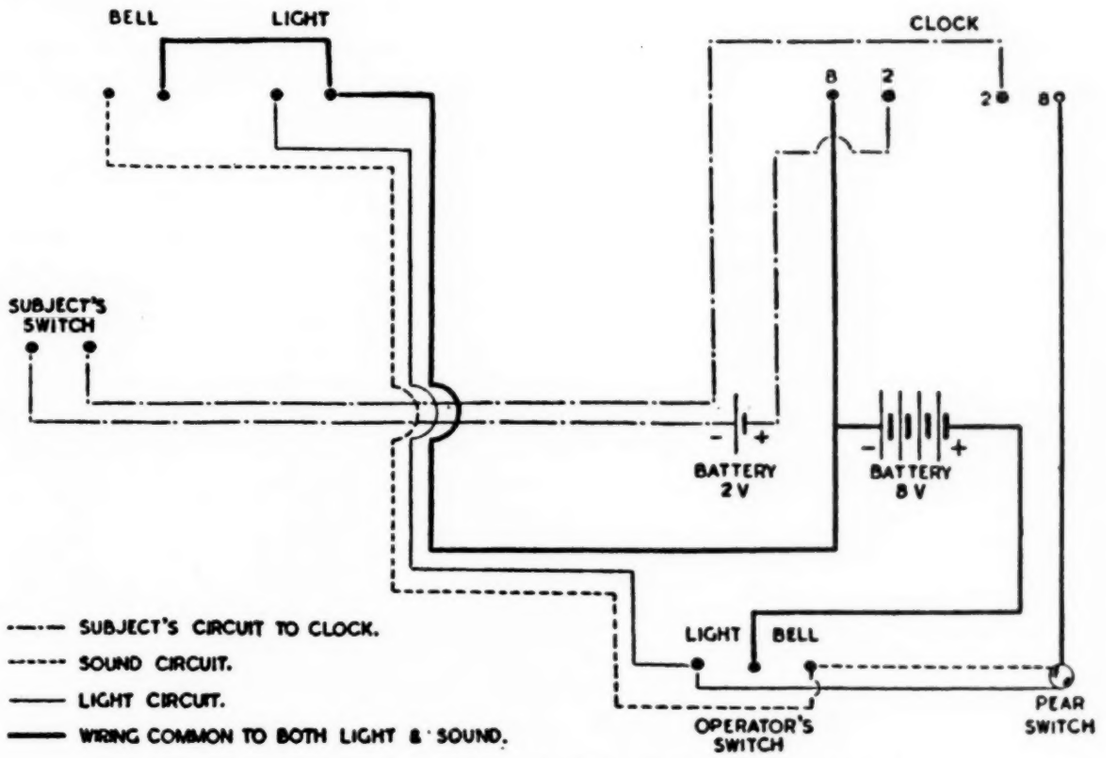

Fig. 1. Diagram of electrical circuits in the apparatus

The first 20 men were given 10 consecutive days' training to try to eliminate the effects of practice, and to give each *S* the opportunity of attaining his 'established normal reaction time.' Having done this it was quite obvious, from an examination of the results, that it was not possible for an individual to attain an 'established normal reaction time,' due probably to minor daily variations in his metabolic state. Mere inspection of the figures showed that there is a small fluctuation on either side of the mean which is not constant for the individual. The effects of practice on a very much larger number of *S*s will be considered below, when it will be found that the conclusion reached by mere inspection of the figures—admittedly a very rough and unscientific method—is borne out by statistical analysis. The additional material on which the effect of practice was assessed was obtained indirectly from other *S*s.

On commencing to analyse the figures it was found that the observations concerned men varying in age from 17 to 36 years. For considering the effect of age this range was obviously too narrow and further recordings from 82 *S*s varying in age from 37 to 53 years were made. Eighteen readings from men of this age group, which had previously been omitted in order to avoid having a straggling tail to the curve of age distribution, were also included. This made a total of 102 observations on this group of older men.

It is hardly necessary to point out that during the actual recording of reaction times precautions were taken to ensure that no extrinsic noises would distract the *S*'s attention. Great care was exercised to transmit the signals at irregular intervals so that there was no possibility of anticipation, at the same time avoiding too long an interval between signals during which the *S*'s attention might tend to wander.

Results

In all, 509 recordings of reaction times to light and sound were made, the mean age of the *S*s being 30.46 years, and the range from 17 to 53 years (Tables I and II). This total number of observations was obtained from men of two age groups. The main contribution was made by a series of 407 observations on *S*s with a mean age of 27.28 years and varying in age from 17 to 36 years (Tables I and II). In addition, 102 readings were taken from men of a mean age of 43.16 and with an age range of from 37 to 53 years (Tables I and II).

TABLE I

Reaction Times to Light and Sound in Hundredths of a Sec.

Number of readings	Mean age	R.T.	Mean	σ
407	27.28	Light	28.64	3.94
84	43.78	Light	29.97	5.675
18	40.22	Light	28.58	2.68
102	43.16	Light	29.72	5.22
509	30.46	Light	28.86	4.25
407	27.28	Sound	18.80	2.94
84	43.78	Sound	21.56	5.67
18	40.22	Sound	16.66	1.46
102	43.16	Sound	20.69	5.53
509	30.46	Sound	19.19	3.63

TABLE II

Range of Readings in Hundredths of a Sec.

Reaction	Mean	Range	Mean age	Range of ages
Light (407)	28.64	19.0 to 42.3	27.28	17 to 36
Sound	18.80	12.1 to 30.4		
Light (84)	29.97	21.1 to 47.6	43.78	37 to 53
Sound	21.56	13.2 to 43.2		
Light (509)	28.86	19.0 to 47.6	30.46	17 to 53
Sound	19.19	12.1 to 43.2		

The mean reaction time to light is 28.86 hundredths of a sec. and it will be noted that the mean values for the two age groups correspond fairly closely to one another and to the mean of all the observations

(Table I). This finding at once suggests that in the case of the reaction time to light there is little relationship between age and reaction time. This is borne out by the coefficient of correlation between reaction time and age, which was +0.27 in the case of the men over 37 years (Table III).

The mean reaction time to sound is 19.19 hundredths of a sec. The mean value in the case of the younger age group is 18.80, and 20.69 for the older men. This, in contradistinction to the light readings, suggests that in older men the age factor may be important, and the coefficient of correlation between age and reaction time to sound in men over 37 years being +0.62 bears this out (Table III).

It appears (Table II) that there is considerable variability in both reaction times, the readings being scattered over a wide range. This, in fact, is what one would expect in view of the known variability of any biological function. However, it can be seen from the histograms (Figs. 2 and 3) that in the case of both series of readings,

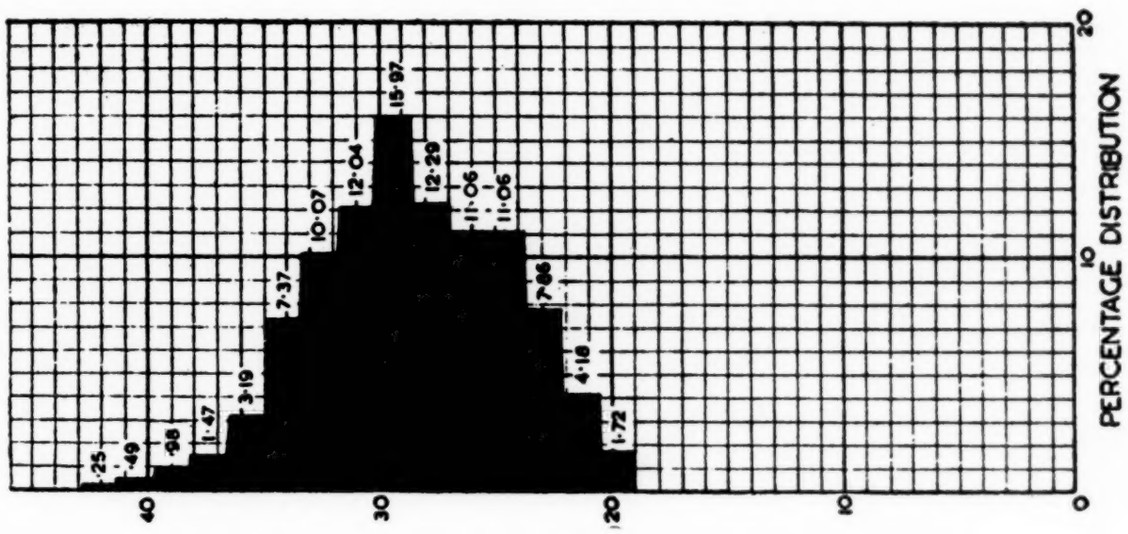

FIG. 2. Histogram showing the distribution of reaction times to light

there is what approximates to a 'normal' distribution, the values being almost evenly distributed on either side of the mean. The figures, of which these histograms are graphic representations, show that in the case of the reaction time to light only 3.9 percent of the readings lie above the 35.0 to 36.5 group, while in the case of sound only 2.96 percent lie above the 23.7 to 24.9 group. This indicates that abnormally high or low reaction times are relatively rare but are encountered.

The true index of variability about the mean is the standard deviation (σ) and it is relatively small in both cases—4.25 for the light reaction and 3.63 in the case of the reaction time to an auditory stimulus (Table I). The coefficient of variation gives a more

accurate picture of relative variability where the means are not of the same order. In this series these coefficients for light and sound are 14.7 and 18.8 respectively, which indicates that relatively the reaction time to sound is rather more variable than the reaction time to light.

The mean values quoted for the reaction times to light and sound are the averages obtained from the sample of the 'universe' examined. The value need not necessarily be the same for all samples of the same 'universe'—the means will vary somewhat. Using the standard error of the mean as a factor we find the true mean will be between 28.48 and 29.24 in the case of reaction time to light, and between 18.87 and 19.51 in the case of reaction time to sound.

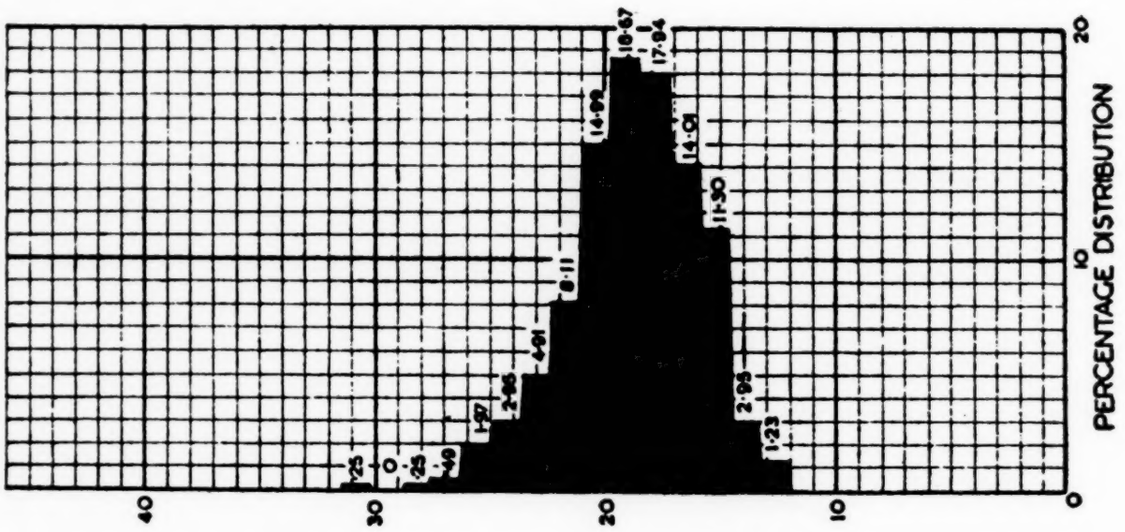

FIG. 3. Histogram showing the distribution of reaction times to sound

The correlation coefficient (r) between reaction times to light and sound is +0.428 (Table III). This figure represents a relatively low degree of correlation but one which is significant, and the standard error is 0.0496 (Table III). This means that there is some degree of relationship between these two reaction times, but that it is not close, though direct. In other words reaction times to sound and light are only partially dependent the one on the other, and one reading does not directly reflect changes in the other.

THE EFFECT OF THE VARIABLES

Age.—The correlation between age and reaction times must first be considered. Reference to Table III will show that between the ages of 17 and 36 years there is a coefficient of +0.142 between age and reaction time to sound, which, while just significant in terms of the standard error, is very low. However, in the older age group

TABLE III

COEFFICIENTS OF CORRELATION

Coefficient of correlation between:	Number of observations	r	Standard error of $r\left(\frac{1}{\sqrt{n-1}}\right)$
Sound and light	407	+0.428	±0.0496
Sound and age (17 to 36 years)	407	+0.142	±0.0496
Sound and age (37 to 53 years)	84	+0.62	±0.109
Sound and age (17 to 53 years)	509	+0.34	±0.044
Sound and hours since rising	423	−0.02	±0.049
Sound and hours since last meal	242	−0.58	±0.064
Sound and numerical order of reading	383	−0.033	±0.051
Light and age (17 to 36 years)	407	+0.321	±0.0496
Light and age (37 to 53 years)	84	+0.27	±0.109
Light and age (17 to 53 years)	509	+0.25	±0.044
Light and hours since rising	423	−0.073	±0.049
Light and hours since last meal	242	−0.08	±0.064
Light and numerical order of reading	383	−0.21	±0.051

the picture changes, because here the correlation between these two variables is represented by a coefficient of +0.62, which is 5.7 times the standard error (Table III). This represents a fair degree of correlation, and these figures indicate that over the age of 37 years, an increase in age is accompanied by some increase in reaction time to sound.

The correlation between age and reaction time to light is represented by a coefficient of +0.25, taking both age groups together (Table III). This figure is just significant, and in the older age group alone the coefficient is of the same order. This is a very low degree of correlation.

Tables have been constructed (Fisher, **6**) giving the value of the coefficient of correlation necessary before significance can be concluded where small numbers of observations are concerned. In the older series there were 84 observations from the same number of individuals—the 18 readings from two men being omitted for the sake of uniformity. The coefficient of correlation between sound and age in this group is +0.62. According to Fisher's table a coefficient of correlation of +0.62 is significant while that of +0.27 may be considered just significant.

There is, therefore, an indication that with age the reaction time to sound tends definitely to increase while that to a visual stimulus is very little if at all affected.

Fatigue.—The influence of fatigue may in certain circumstances be very important. Each individual spends the day in his own way, and some persons tire more quickly than others. The difficulty arose of assessing fatigue and of measuring it by any method that could be expressed numerically, so it was decided that, on the assump-

tion that a man is at his best after a period of sleep, a fair and generally acceptable measure of fatigue would be the number of hours since rising to start the day. In a series of 423 observations taken from 83 individuals, and covering up to 21½ hours since rising, the coefficients of correlation between the variable and reaction times to sound and light are respectively −0.02 and −0.073 (Table III). This signifies that fatigue, as estimated by the method stated, has no relationship to visual and auditory reaction times.

Proximity to a meal.—The condition of the alimentary canal is known to influence many physiological functions, and a full stomach has a well-known reputation, based on sound physiological principles, for producing a damping of mental and bodily activity. This variable was studied in a series of 242 observations. The condition of the alimentary canal at the time of the test was assessed in terms of the lapse of time since the last meal. The coefficient of correlation between the reaction time to sound and the number of hours since the last meal is −0.58 (Table III), which is an inverse relationship and means that the nearer to a meal, and therefore the greater the alimentary activity, the slower the reaction time. This figure indicates moderate correlation and is definitely significant. Strangely enough, the correlation with reaction time to light is −0.08 (Table III), which is not significant and can be ignored. It appears therefore that a full stomach, to some extent at least, slows the reaction time to sound but has no effect on reaction time to light.

Practice.—As stated above, it was obvious from inspection of the figures recorded by the first 20 *S*s that practice did not enable a man to attain an 'established normal reaction time.' If the reverse had been true, as postulated by Jonnard and Maire (**10**) and by Cheney (**3**), then one would have expected a high degree of correlation between reaction times and practice, as assessed by the numerical order of the reading. Based on 383 observations the coefficient of correlation between reaction time to light and the numerical order of the reading is −0.21 (Table III). This figure is approximately four times the standard error (Table III), and is therefore, significant, though it represents a low degree of correlation. The coefficient of correlation between practice and reaction time to an auditory stimulus works out at −0.033, which is not significant (Table III). This discrepancy between these two coefficients may be explained by two theories. The visual paths in the brain are more complex and involve a larger number of synapses than the auditory paths, and this may account for the fact that there is a slight correlation between reaction time to light and practice in operating the machine. An alternative explanation is that, as the reaction time to light was always tested first, this may have served as practice, thus eliminating

this factor from the reading to an auditory stimulus which followed it. The second theory could be subjected to proof by repeating the observations on a fresh series of *Ss* but taking the sound reading first. This point was not pursued further.

Conclusions

Figures for the reaction times to light and sound using the apparatus described above have been arrived at, and while the range of the readings is considerable, the standard deviations are comparatively small. In terms of the coefficient of variation the reaction time to sound is more variable than the reaction time to light. The two quantities are only partially dependent on one another, and one reaction time does not directly reflect changes in the other. As age advances there is a significant increase in reaction time to sound—a finding which corresponds with the experience of Bellis (**2**) and Cheney (**3**)—while the degree of correlation between reaction time to light and age is low and of no practical importance. Ordinary degrees of fatigue have no influence on reaction times. A loaded stomach influences to some extent at least, the reaction time to sound, the relationship being inverse, but has no effect on reaction time to light. Achievement of an 'established normal reaction time' as a result of practice was not found to be possible. Practice has no effect on reaction time to an auditory stimulus and only a slight influence on the speed of response to a visual signal.

Summary

1. An apparatus for recording visual and auditory reaction times is described.

2. The reaction times of 178 male *Ss* varying in age from 17 to 53 years are recorded under different conditions.

3. The influence of certain variables on these reaction times is considered statistically.

4. Reaction times to light and sound are only partially dependent.

5. The reaction time to sound tends to increase with age, and with proximity to a meal, but is unaffected by practice or fatigue.

6. The reaction time to light improves slightly with practice, and is unaffected by ordinary degrees of fatigue, by proximity to a meal, or by age.

The experimental work described above was carried out with material provided by the City of Sheffield Watch Committee and I wish to make grateful acknowledgment of the facilities provided. My thanks are due also to Group Captain G. Struan Marshall, Officer Commanding, Central Medical Establishment, Royal Air

Force, through whose good offices I was able to obtain on loan the d'Arsonval clock used. To the officers and men of the City of Sheffield Police Force, who so willingly attended for the experiments in their off-duty time, I am very indebted; without their willing coöperation the work could not have been undertaken.

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IDENTIFICATION OF POSTHYPNOTIC SIGNALS AND RESPONSES

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Erickson (1) has described a series of experiments in which, as a result of instructions given to the *S* during a deep hypnotic trance, various phenomena illustrating psychic determinism were demonstrated. In his opening remarks the author states:

> The subject who was used for many of these demonstrations had frequently before volunteered for similar purposes. He knew nothing however, of the plans for these experiments; they represented situations which were entirely new and problems with which he had never before been confronted. . . . In his approach to such demonstrations, this subject customarily reacted in a way which was fairly characteristic for many others. Ahead of time he often appeared to be resentful and anxious, or over-eager about the impression which he and the experimenter would make (1, p. 338).

Three questions arise from Erickson's procedure of using the same subject throughout the experiments. Can the experienced *S* become aware of the fact that he is carrying out a posthypnotic response while reacting to it? If so how does he become aware of it? If the *S* can detect the posthypnotic response or signal, in what way could this affect the results? The present study represents an exploratory investigation of these problems.

Procedure

In actual practice, identification of the posthypnotic response may often result from the latter's unusual or bizarre nature. In order to avoid this possibility and in an attempt to make the conditions of recognition as difficult as possible, posthypnotic signals and responses of an everyday commonplace nature for the *S* were used. For this purpose A. H. and M. K., two close friends living in the same house and both majoring in psychology, collaborated with the senior author in the present experiment. Any of their casual daily remarks or actions might thus serve as the posthypnotic signal or posthypnotic response. A. H., the hypnotic subject (*O*), showed all the phenomena of the deep hypnotic state and had been used for demonstrational purposes on several occasions. M. K., who acted as hypnotist (*E*), had been carefully instructed and supervised in the technique of hypnotic induction.

The routine adopted was as follows: *E* hypnotized *O* every other night prior to their retiring, inducing the hypnotic state during a period of 10 min. The posthypnotic signal and response were introduced, amnesia [1] was suggested, and the *S* was then awakened. On no occasion did *O* recall the instructions given during the trance, nor did spontaneous recall occur at any period.

At the commencement of the experiments, *O* was asked to identify, if possible, any posthypnotic signal or response that might occur in the course of the day following the hypnotic session.[2] *E* was careful not to give *O* any clue to the nature of the posthypnotic signal, and

[1] This was in the nature of an added precaution inasmuch as *O* showed spontaneous amnesia.

[2] Before the start of the experiment *O*, on the basis of her previous experience, believed that she would succeed.

similarly *O* was careful not to indicate to *E* any recognition of posthypnotic signals or responses. Observations by *O* and *E* were kept in separate diaries and neither definitely knew of the progress of the experiment until its termination.

Nine hypnotic sessions were held. Two of these sessions constituted control periods, i.e., the routine hypnotic procedure was carried out, but no posthypnotic instructions were given. The posthypnotic signals, the time they were given and the required responses were as follows:

	Signal	Response
1.	"Have you heard from Eddie lately?" (noon)	To pull the lobe of her ear when answering
2.	"Please pass me a bowl of soup" (noon)	To rub her chin
3.	"May I borrow a kerchief?" (10 P.M.)	To give her one and to tell her she can keep it
4.	"Would you like to play bridge?" (8 P.M.)	To say 'yes, in about 5 minutes'
5.	"How many psychology reports are you behind?" (11 P.M.)	To say 'sh' and to put her finger over her mouth
6.		Control
7.	Seeing *E* chewing gum (11 A.M.)	To ask *E* for a piece of gum
8.	Awakening in the morning (9 A.M.)	To go to *E*'s room and ask for a cigarette
9.		Control

Results

O correctly identified the 7 posthypnotic responses, 6 of the 7 posthypnotic signals, and also the absence of signal and response in the 2 control periods. In the identification of posthypnotic signals *O*'s diary indicates that in 3 cases (nos. 3, 4, 5) initial recognition resulted directly from a 'déja vu' quality of the signal. In the remaining cases (nos. 1, 2, 7, 8) the 'automaticity' of the response indirectly enabled *O* to reason back to the posthypnotic signal[3] in all cases but no. 8, where the indeterminate nature of the signal made its detection difficult. Identification of the posthypnotic responses resulted in every case from the 'automatic' nature of the response. It follows from the above two statements that identification in nos. 3, 4, and 5 was based on both 'automaticity' of response as well as the 'déja vu' character of the signal.

To illustrate more fully the meaning of 'déja vu' and 'automaticity' the following sample reports from *O*'s diary are given:

(No. 3) "The cue was the kerchief. Here I spotted the cue. I do not really know how, except that the minute I heard it, it seemed to me that somewhere I'd been asked it or heard it before."

(No. 4) "The cue was asking me to play bridge. Here I spotted the cue also. The same feeling about the verbal response occurred as in the response telling Pat (*E*) to keep the fascinator. First I spotted the cue as having heard it somewhere before. Then the response about giving

[3] *O* reported that posthypnotic verbal responses were more easily identified than posthypnotic motor responses since they were more 'automatic' in nature.

me 5 minutes did not come as the result of an impulse to say this, but was entirely automatic. On looking it over I realized it had been made for no logical reason. It just burst forth without reason or thought. I felt more or less as though I'd been trained to say it. And then I reasoned back to verify my suspicion about the cue."

(No. 2) "The cue was asking me to pass something (soup) at the dinner table. In the course of the meal I had a strong impulse to scratch my chin. For anyone who has been hypnotized several times, at least for me, I would not confuse this impulse with a quite normal one. Through backward reasoning I chose Pat's (*E*) asking me to pass her the soup as the cue, since it was not until after that that the impulse arose. I realized what the impulse had been after I'd obeyed it."

(No. 8) "The response was getting the cigarette from Keegan. I wasn't sure of the cue. I felt the impulse to go down to Pat (*E*). I knew this had been the response, but I couldn't figure out the cue. I thought perhaps it might have been her calling me, but that I doubted. It was odd, on my way downstairs I didn't think of asking her for a cigarette, yet when I got there it just flowed out. I knew when I came up that it had been a response, for I had a pack of cigarettes on my own dresser. Yet even through reasoning backward then I couldn't figure out the cue."

(No. 6—control) "Didn't notice any."

Discussion

These results confirm Estabrooks' (**2**) mention of two sophisticated *S*s who were able to detect the posthypnotic response in the course of reacting it. One of these *S*s describes his experience as follows:

> I just feel it in my bones. Sort of an urge to do it and a very uncomfortable feeling when I resist. That feeling would never come from anything else (**2**, p. 75).

While identification of either signal or response occurred in every case, this does not indicate a corresponding breakdown in amnesia. In the 'déja vu' cases amnesia may be considered to have yielded at the level of recognition. In the remaining cases it is to be emphasized that identification of posthypnotic responses is a result of reasoning from the 'automaticity' to the response. This process rapidly becomes short-circuited so that the identification of the response, which is in terms of its relationship to the quality of 'automaticity,' and not the *S*'s previous acquaintance with the response, is almost immediate.

Two considerations suggest that the posthypnotic response is a more constant and reliable indicator than the posthypnotic signal. In the present experiment it is possible that initial identification by the 'déja vu' character of the signals resulted from failure to obtain sufficient depth of hypnosis on these trials. A second factor in connection with the posthypnotic signal is that its detection is difficult where it is of an indeterminate nature as exemplified in signal no. 8. Neither of these points relate to the detection of the posthypnotic response.

In Erickson's (**1**) procedure the nature of the specific posthypnotic responses was left to the *S*, i.e., only a 'general set' was given. Under these conditions it is quite likely that the trained *S* gains insight

into the nature of his behavior early in the period of posthypnotic response[4] and that subsequently his behavior reflects a conscious rather than an unconscious desire to resist or coöperate with the aim of the experimenter. With regard to the first possibility Wells (3) has shown that with proper hypnotic technique and proper selection of *S*, inhibiting the response is very difficult if not impossible.[5] The methodological problem enters then in regard to the second possibility, i.e., of the *S*s embellishing the posthypnotic response, especially if the *S* is "overeager about the impression which he and the experimenter would make" (1, p. 338). The results obtained in this study suggest that a naive *S* is best used in the investigation of posthypnotic behavior. It would also seem to follow as a corollary to the above results that rationalization for the carrying out of posthypnotic responses should be characteristic only of the naive *S*.

Summary

The present experiment indicates the ability of an experienced somnambule to identify posthypnotic signals and responses by the 'déja vu' character of the signal and the 'automatic' nature of the response, or both. This factor should be taken into consideration in the study of posthypnotic behavior.

(Manuscript received August 4, 1945)

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[4] Detection is further simplified in Erickson's experiments by the fact that the posthypnotic signal followed within a short period of awakening the *S*.

[5] In the present experiment posthypnotic responses were carried out even where posthypnotic signals were recognized as such.